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Central Bank Communication about Climate Change *

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Abstract

This paper applies natural language processing to a large corpus of central bank speeches to identify those related to climate change. We analyze these speeches to better understand how central banks communicate about climate change. By all accounts, communication about climate change has accelerated sharply in recent years. The breadth of topics covered is wide, ranging from the impact of climate change on the economy to financial innovation, sustainable finance, monetary policy, and the central bank mandate. Financial stability concerns are touched upon, but macroprudential policy is rarely mentioned. Direct central bank action largely revolves around identifying and monitoring potential risks to the financial system. Finally, we find that central banks tend to use speculative language more frequently when talking about climate change relative to other topics.

Keywords: Financial stability; Transparency; Central bank mandate; Green finance; Natural language processing; Central bank speeches
JEL Classifications: E58; E61; Q54

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1 Introduction

Climate change is an important priority for central banks around the world. As evidence, membership in the Network for Greening the Financial System (NGFS) has increased from eight central banks and supervisors at its inception in late-2017 to over one hundred as of early-2022. In order to join the NGFS, members are required to publicly acknowledge that climate-related risks are a potential source of financial instability. As such, the number of central banks that have acknowledged that climate-related risks fall within their supervisory and financial stability mandates has exploded during a short five year period.

At the same time, climate change is a complex topic that is outside the traditional areas of expertise for central banks. The interaction between climate and economic activity is not well understood and occurs over a longer time horizon than central banks typically consider. Little is known about propagation of climate-related risks through the financial system. More fundamentally, there are significant data gaps which pose challenges for risk management for micro- and macroprudential supervisors alike in addition to financial market participants more generally. Taken together, these complications put central banks in a difficult position. How can they establish credibility for being responsive to climate change when relatively little is known about how it interacts with the real and financial economy?

One approach is to build credibility through communication. Central bank communication is increasingly important in achieving monetary policy objectives.[1] Moreover, recent research has shown that *how* central banks approach communication matters greatly, not only for achieving desired policy objectives but also for managing public perception about the institution itself. For example, Haldane and McMahon (2018) and Kryvtsov and Petersen (2021) show that communication is more effective when central banks use simple, relatable language. Bholat, et al. (2019) shows that simple, relatable communication helps to build public trust and improves people's perception of the central bank. This research suggests that how central banks approach talking about climate change is crucially important as they learn more about its effects on financial markets and the broader economy. At this point, however, we know very little about how central banks approach communication about climate change. This paper takes a first step toward filling this gap in the literature. We apply natural language processing techniques to a corpus of over 17,000 central bank speeches to identify the subset that are climate-related. Using these climate-related speeches, we analyze not only what central bank actually talk about when they talk about climate change, but also how they talk about the topic. We pay particular attention to macroprudential tools in the context of the financial stability implications of climate change, but a number of other topics are covered as well. Our analysis can help promote more effective communication about risks associated with climate change and is critical for clarifying the role of central banks in addressing the issue.

There are three main conclusions. First, by all accounts central bank communication about climate change has expanded sharply in recent years. This is true at the extensive margin (the number of speeches focusing on climate change) as well as the intensive margin (the extent to which climate-related topics are covered within a given speech). The sharp growth in climate-related communication applies to central banks

[1] See, for example, Blinder, et al. (2008) for an early survey of the literature. More recently, a number of papers have studied the effect of central bank communication on monetary policy transmission, including Guthrie and Wright (2000), Gürkaynak, et al. (2005), Nakamura and Steinson (2018).

in advanced and emerging market economies alike, pointing to the global nature of the problem.

Second, the breadth of climate-related topics addressed by central banks is wide, ranging from the impact of climate change on the economy to financial innovation, sustainable finance, monetary policy, and the central bank mandate among other topics. Financial stability concerns are touched upon, but the speeches rarely discuss macroprudential policy. At this point, public communication regarding direct central bank action to address climate-related financial stability risks centers on identifying and monitoring potential risks not only from macroprudential perspective but also for microprudential supervision. Climate scenario analysis or stress testing is one such tool discussed in this context, but central banks also touch on other actions including setting supervisory expectations on financial institutions' climate risk management and enforcing mandatory disclosure of exposure to climate-related risks. A handful of central banks discuss actions related to their own carbon footprint—either the composition of the balance sheet or through responsibilities associated with management of domestic pension funds——but not in the context of macroprudential policy.

Finally, a third conclusion relates to the nature of the language used by central banks to communicate about climate. We present statistical evidence indicating that central banks tend to use "speculative language", or language that indicates uncertainty, more frequently in climate-related speeches relative to other speeches. Given the complexity of the topic and the fact that climate change is not an area of traditional expertise for central banks, some degree of ambiguity about the topic in public communication seems appropriate. Nevertheless, previous studies of central bank communication have shown that clarity of language influences the credibility of the message.[2] Going forward, as central banks deepen their knowledge about climate-related risks, the language used in public communication should evolve with the goal of providing sharper communication with more precise language. Developing climate-related communication in this direction can help establish credibility that central banks are being responsive to climate change.

This paper contributes to a growing literature that considers the role that central banks in responding to climate change. McKibbin, et al. (2021) argues that climate change considerations should be incorporated into monetary policy decisions. Campiglio, et al. (2018) makes the case that the financial stability implications of climate change and the transition to a low-carbon economy warrant consideration in setting financial regulation and central bank policies, more generally. Chenet, et al. (2021) goes one step further. Building on Weitzman (2009), these authors argue that the severity of future shocks due to climate change are so potentially devastating that strong *ex ante* macroprudential policy which precludes investment in carbon-intensive assets is warranted. In contrast, Hansen (2022) contends that in order to maintain credibility, central banks need to be clear about their ambitions and execution and can best do so by adhering narrowly to their mandated roles.[3] The author makes the case that because most effective climate policy tools are in the fiscal, rather then the monetary, toolkit. As such, if central banks pursue policies to combat climate change they risk undermining their own credibility. Finally, Bolton, et al. (2020) argues that central banks need to work proactively with other policymakers and institutions to better understand and address the increasing uncer-

[2]In addition to Haldane and McMahon (2018), Kryvtsov and Petersen (2021) and Bholat, et al. (2019) discussed above, see also Montes and Nicolay (2017).

[3]Dikau and Volz (2021) highlight significant differences in how climate objectives do and do not fit within central banks mandates across different countries. For some countries actively engaging in climate-related policies is well within the mandate while for others the case is not so clear.

tainly associated with climate change to ensure long run financial and price stability. This paper contributes to this literature by focusing on how central banks communicate about climate change regardless of whether or not they are actively considering policies to address it. In keeping with the conclusions of both Hansen (2022) and Bolton, et al. (2020), having a better understanding of how central banks approach communication about climate will help to improve the quality of that communication and, in doing so, makes central banks engagement more credible and transparent.

This paper also relates to a body of literature, surveyed in Bholat, et al. (2015), that uses natural language processing to understand central bank communication. A number of studies focus on extracting information from speeches, publications, or policy statements to see if there are implications for financial market activity. For example, Born, et al. (2014) and Correa, et al. (2021) both analyze how information conveyed through Financial Stability Reports affects financial markets. Shapiro and Wilson (2021) use sentiment analysis to estimate central bank preferences using FOMC statements. Kawamura, et al. (2019) find that ambiguity in central bank communication is related to financial market volatility. This paper differs from these contributions in that we study a specific topic (climate change) and the use of language in communication focused narrowly on that topic. Within the text analysis literature, our paper is an application of topic detection techniques. There are a handful of studies that also apply topic modeling to central bank communication, but topic modeling is used in these papers either for dimension reduction (Hansen, et al., 2018, Hansen, et al., 2019, and Hansson, 2021) or for identifying the main or most frequent topics addressed in communication (for example, Moschella and Pinto, 2018, Armelius, et al., 2020, and Benchimol, et al, 2021). We contribute to this literature by developing a methodology to identify central banks communications about a narrowly defined topic. Although we are particularly interested in climate change, the methodology developed here could be applied to more broadly.

The remainder of this paper is organized as follows. The next section offers details on the full set of speeches used in our analysis. In Section 3 we describe a novel methodology for identifying climate-related speeches. Section 4 analyzes these climate-related speeches with particular attention on the role of macroprudential policy in addressing climate-related financial stability risks. Section 5 analyzes some qualitative aspects of central bank communication about climate change. Finally, Section 6 concludes

2 Central Bank Speech Dataset

Our starting point is the set of all central bank speeches available from the Bank of International Settlements (BIS) over the twenty-five year period from January 1997 to December 2021.[4]

Table 1 presents some summary statistics. Since 1997, a total of 17,405 speeches were delivered by representatives from 108 different central banks. Roughly 70 percent were given by central banks in advanced economies with an average of about 17 speeches per advanced economy central bank in any given year.[5] That said, there is considerable dispersion in frequency. For example, larger central banks such as

[4]The BIS collects transcripts of speeches in English that are available from central banks' websites. For some central banks, the database only covers a subset of the total number of speeches available on their websites due to selected reporting from their media offices. The database is updated on a daily basis and is available at https://www.bis.org/cbspeeches/.

[5]Our split between advanced and emerging market economies is informed by IMF classification for their World Economic

the European Central Bank (ECB) and the Federal Reserve System (Fed) tend to be more active, giving an average of close to 90 speeches per year, whereas smaller advanced economy central banks such as the National Bank of Slovakia, the Bank of Slovenia, and the Central Bank of Cyprus communicate less frequently.[6] All told, the five most active central banks—the ECB (2,337 speeches total), the Fed (2,073), the Deutsche Bundesbank (753), the Bank of Japan (711), and the Bank of England (708)—account for over half the speeches given by advanced economy central banks in our dataset.

Central banks in emerging market economies account the remaining 30 percent of all speeches, with the average emerging market economy central bank giving about 8 per year. The most active are the Reserve Bank of India (837 speeches total), the Central Bank of Malaysia (485), the Central Bank of the Philippines (484), the South African Reserve Bank (382), the Bank of Albania (281), and the Bank of Thailand (219). Together, these six central banks account for half of all speeches given by emerging market central banks.

Table 1: Summary statistics, All speeches

	# of Central Banks	# of Speeches	Avg. # of Speeches Annually per Bank	Avg. # of Words per Speech
Advanced Economy	37	12,016	16.8	1,037
Emerging Market Economy	71	5,389	7.8	817
Total	**108**	**17,405**	**12.4**	**969**

Source: Author's calculations.

Communication is skewed toward advanced economy central banks not only in the number of speeches (with over twice as many speeches per bank annually), but also in the length of the speech. The last column of Table 1 shows that advanced economy central bank speeches average about 1,000 words while speeches by emerging market central banks average 20% fewer words at just under 800.[7]

Since 2005, Figure 1 shows the number of advanced economy central banks that have given at least one speech in a given year averages about 30 (red line in the top left panel). For emerging markets (green line) the number is slightly lower despite the fact that there are nearly twice as many emerging market central banks (71 as opposed to 37 in the advanced economies). The top right panel shows the total number of speeches for a given year. For emerging markets this number has stayed roughly constant since 2005, but it has steadily increased in the advanced economies. This increase reflects a near doubling of the average number of speeches per advanced economy central bank from about 10 to over 20 per year (bottom left

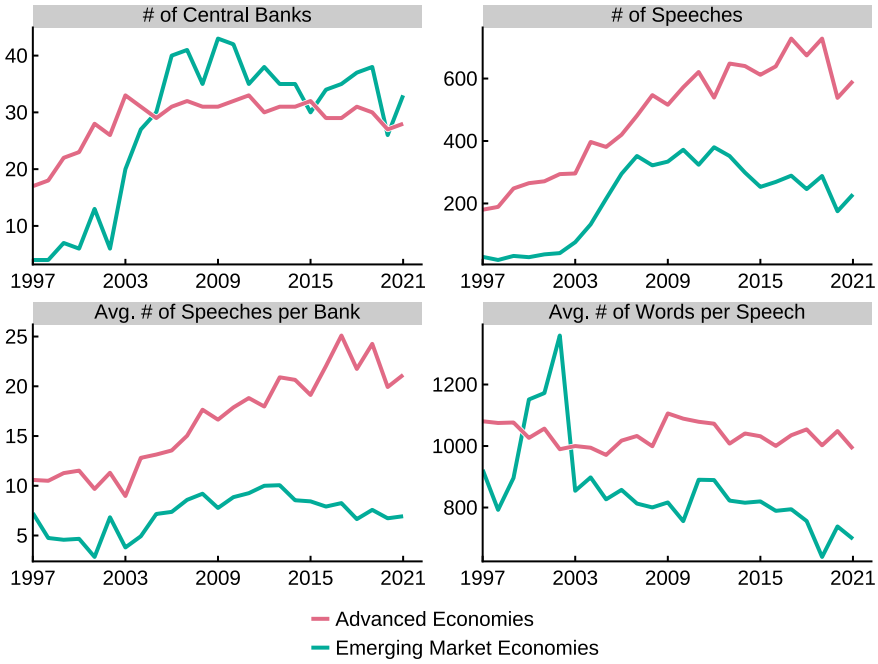
Outlook (see https://www.imf.org/external/pubs/ft/weo/2021/01/weodata/groups.htm). A complete list of central banks with at least one speech in the data set is given in Appendix A.

[6]Smaller central banks (advanced and emerging market economies alike) may be less likely to report speeches to the BIS (translating the speech to English may be costly, small central banks may have fewer representatives available to give speeches or may simply choose to make fewer speeches made available on their websites, etc). Accordingly, some cross-bank comparisons need to be interpreted with caution.

[7]The number of words are counted after the raw text is pre-processed. We follow standard practice in the text analysis literature by dropping extremely common words (so-called stopwords) and creating noun-phrases by Part-of-Speech (POS) tagging techniques. See Appendix B.1 for details.

panel) and is in keeping with a ongoing trend toward greater central bank transparency. Finally, the lower right panel shows speech length has stayed roughly constant at about 1,000 words for advanced economy central banks, while speeches given by central banks in emerging market economies have gotten shorter over time.

Figure 1: Central bank speeches over time, 1997-2021



Source: Author's calculations.

3 Identifying Climate-related Speeches

Using this corpus of speeches, we identify those that are "climate-related". A "climate-related speech" is a speech given by a representative of a central bank that discusses the impact of climate change on the economy and/or the financial system. Ideally, we would identify these speeches using off-the-shelf tools from the text analysis literature that focus on "classification" or "topic identification" but, for reasons discussed in the next subsection, this is not practical. So, we develop our own methodology.

3.1 Existing Approaches for "Topic Identification"

There are three approaches commonly used in the text analysis literature to classify text on a topical basis.[8] The first is to use what is known as an *unsupervised topic model*. This approach is most useful when the topics contained in the corpus are largely unknown to the researcher. In this case, unsupervised topic models are effective at reducing a large quantity of text down to a more manageable set of categories in a

[8]Grimmer and Stewart (2013) and Gentzkow, Kelly and Taddy (2019) provide surveys of this literature.

process known as dimension reduction. One of the most widely used topic models is the Latent Dirichlet Allocation (LDA), introduced by Blei, Ng, and Jordan (2003). Owing to its simple structure, LDA can be easily applied as a dimension reduction tool and has been used with increasing frequency in the economics literature.[9] However, LDA (and unsupervised topic models, more generally) does not easily lend itself to our task because the objective here is to identify text related to a very specific, and relatively new, topic. Unsupervised methods offer no guarantee that climate change will be one of the topical categories identified through the dimension reduction. In fact, given that climate change is a topic that central banks have only recently started to address, it is unlikely that unsupervised methods would be effective at being able to identify climate-related speeches.[10]

An alternative approach is to use *supervised machine leaning* techniques such as text regression, including linear and non-linear techniques, or the Naive Bayes Classifier.[11] In contrast with unsupervised topic models, this approach is appropriate when the researcher knows the topics of interest ahead of time and has a small sample of texts that are meaningfully related to the topics of interest readily available.[12] In this case, the sample texts can be used to train computational models to efficiently identify these known topics in the larger corpus. For our purposes, while we do know the topic of interest ahead of time (climate change), we do not have an initial set of speeches that have already been identified as definitively "climate-related" to serve as a training set.

The third approach is known as a *dictionary approach* which involves using a pre-established dictionary, or a set of keywords specified by the researcher, to classify texts into known categories. The dictionary approach is most appropriate when there is a strong and reliable prior belief that a certain topic is present in the text but information to identify the topic is limited. Examples include cases in which the topic of interest does not match with the factor structure of unsupervised methods or when there is no training data available to fit a supervised model. In principle, our interest in identifying climate-related speeches fits neatly into these examples, so the dictionary approach seems promising.

However, the challenge we face is that it is not clear what keywords are best to use to construct the dictionary necessary to identify climate-related speeches. Existing studies in economics and finance that use the dictionary approach do not face this problem. For example, studies on the impact of sentiment on economic and financial outcomes benefit from pre-determined dictionaries that are widely available to classify text based on sentiment.[13] Some studies that branch outside of sentiment analysis do create custom dictionaries. A well-known example is the Economic Policy Uncertainty Index constructed by Baker, Bloom, and Davis (2016).[14] Another example is Correa, et al. (2021), which creates a dictionary tailored

[9]Examples include Armelius, et al. (2020), Benchimol, et al. (2021), Hansen and McMahon (2016), Hansen, et al. (2018), and Hansen et al. (2019), and Larsen, et al. (2021).

[10]There are a variety of extensions that relax the strong assumptions of LDA, such as the dynamic topic model (Blei and Lafferty, 2006), the correlated topic model (Blei and Lafferty, 2005), or the structural topic model (Roberts, et al., 2013). While these methods may help with our specific application, they all are still limited by the fact that they are unsupervised. Unsupervised methods offer no guarantee that one of the identified topics will be climate-related. Some form of supervision seems necessary to achieve this objective.

[11]Linear text regression methods include penalized linear models such as Lasso, Ridge, and Elastic Net regressions. Non-linear methods include generalized linear models (GLM), support vector machine (SVM), regressions trees, and deep learning.

[12]Gentzkow and Shapiro (2010) and Gentzkow, Shapiro, and Taddy (2019) are examples of papers that use this approach.

[13]See, Tetlock (2007), Loughran and McDonald (2011), Bollen, et al. (2011), and Wisniewski and Lambe (2013) among others.

[14]This index is constructed by counting news articles that contain the following triple: "economic" or "economy"; "uncertain"

to a financial stability context. As noted in Gentzkow, Kelly, and Taddy (2019), creating a dictionary from scratch typically involves selecting keywords on an *ad hoc* basis. In the case of climate change, using an *ad hoc* approach could lead to mis-identification, so manual validation is required to ensure the keywords actually deliver the types of speeches in which we are interested. This is prohibitively time consuming given the size of our corpus.

3.2 Our Methodology

Our solution is to come up with our own methodology to identify climate-related speeches using an automated approach for topic detection through keywords.[15] A detailed description is provided in Appendix B, but the general strategy is as follows. Starting with a single seed word, "climate change", we use the method of Laver, et al. (2003) and Watanabe (2018) to create a score for all words (after pre-processing) in the corpus. The word score is constructed by comparing the frequency with each individual word shows up in speeches that *do include the seed word* relative to the frequency with which the word shows up in speeches that *do not include the seed word*. Once we have a score for every word in the corpus we use these word scores to construct a measure of the propensity of a given speech (which is just a collection of all the different words that we score) to be "climate-related" by taking a weighted average of word frequency using the word scores as weights.[16] We then select a minimum cutoff of zero and use that as an initial criteria for identifying what we call an unrefined set of climate-related speeches. As shown in Panel A of Table 2, this initial stage identifies 2,337 speeches that have a speech score greater than zero that are potentially "climate-related".

In practice, many of the speeches identified in this initial stage are indeed climate-related but some are misidentified, especially when the speech score is close to the threshold.[17] We deal with mis-identification by introducing an iterative refinement stage, detailed in Panel B of the table.

or "uncertainty"; and one or more of "congress", "deficit", "Federal Reserve", "legislation", "regulation" or "White House".

[15] Laver, et al. (2003) introduced an automated method using a scoring technique (called Wordscores) that, in a political economy context, detects political actors' positions with minimal human intervention. King, et al. (2017) shows that a supervised algorithm can be used to detect a set of keywords that identify topics with greater accuracy than keywords generated using *ad hoc* methods. Watanabe (2018) and Watanabe and Zhou (2020) make similar arguments using an automated methodology with scoring techniques.

[16] For all speeches in the corpus, the score averages −0.27 with a standard deviation of 0.37 and ranges from −2.16 to 3.70. A positive score indicates a speech that contains many words that show up frequently alongside the seed word "climate change", a score of zero indicates the use of words in the speech are neutral to the seed word, and a negative score indicates the words used in the speech tend not to also be used in speeches that include the seed word.

[17] The scoring method treats words simply as data rather than requiring any knowledge of their meaning as used in the text. While this is useful for automation, some degree of mis-identification is inevitable. Grimmer and Stewart (2013) point out that careful pre-processing of texts will mitigate the issue because the result will depend strongly on the reference texts that are used. Lowe (2008) shows potential biases in the scoring method, although it can be reasonably small if the results seem plausible.

Table 2: Refinement process to identify climate-related speeches

	Number of speeches	Speech Score Statistics				Keyword Identified in Exploration Set
		Mean	St. Dev.	Min.	Max.	
All speeches	**17,405**	**-0.27**	**0.37**	**-2.16**	**3.70**	
Panel A: Initial Identification						
Climate-related speeches (Before Refinement)	**2,337**	**0.34**	**0.52**	**0.00**	**3.70**	
Panel B: Refinement Stage						
High score speeches used for keyword exploration	427	1.23	0.65	0.48	3.70	
Iteration 1 (s_1 =["Climate Change"])						
Speeches identified by s_1	373	1.30	0.66	0.48	3.70	
Exploration set	54	0.77	0.38	0.48	1.92	"Green Finance"
Iteration 2 (s_2 =[s_1 | "Green Finance"])						
Speeches Identified by s_2	389	1.29	0.68	0.48	3.70	
Exploration set	38	0.67	0.30	0.48	1.92	"Climate-related Risk"
Iteration 3 (s_3 =[s_2 | "Climate-related Risk"])						
Speeches Identified by s_3	393	1.29	0.65	0.48	3.70	
Exploration set	34	0.62	0.21	0.48	1.55	"Paris Agreement"
Iteration 4 (s_4 =[s_3 | "Paris Agreement"])						
Speeches Identified by s_4	395	1.28	0.65	0.48	3.70	
Exploration set	32	0.61	0.21	0.48	1.55	"Climate Policy"
Iteration 5 (s_5 =[s_4 | "Climate Policy"])						
Speeches Identified by s_5	396	1.28	0.65	0.48	3.70	
Exploration set	31	0.61	0.21	0.48	1.55	"Climate Risk"
Iteration 6 (s_6 =[s_5 | "Climate Risk"])						
Speeches Identified by s_6	397	1.28	0.65	0.48	3.70	
Exploration set	30	0.61	0.21	0.48	1.55	"Low-carbon Economy"
Iteration 7 (s_7 =[s_6 | "Low-carbon Economy"])						
Speeches Identified by s_7	398	1.28	0.65	0.48	3.70	
Exploration set	29	0.61	0.22	0.48	1.55	"Carbon Emission"
Iteration 8 (s_8 =[s_7 | "Carbon Emission"])						
Speeches Identified by s_8	399	1.28	0.65	0.48	3.70	
Exploration set	28	0.58	0.12	0.48	1.02	"Green Bond"
Iteration 9 (s_9 =[s_8 | "Green Bond"])						
Speeches Identified by s_9	400	1.28	0.65	0.48	3.70	
Exploration set	27	0.56	0.09	0.48	0.87	$\emptyset$
Panel C: Final Identification						
Climate-related speeches (After Refinement)	**555**	**0.98**	**0.73**	**0.00**	**3.70**	

Source: Author's calculations.

This refinement focuses on the subset of 427 speeches that have a speech score greater than two standard deviations over the mean for all speeches (this is roughly equivalent to any speech with a score that falls in the top 2.5% of the distribution of all speech scores). We use this subset to identify a set of keywords related to climate change in an iterative process. The initial iteration uses a dictionary comprised of the single keyword "climate change" to identify 373 speeches (87% of the 427 total high score speeches) that

include this keyword, leaving 54 high score speeches that can not be identified. We use these later speeches as an "exploration set" from which we select the most important climate-related keyword, where importance is judged by frequency (i.e., the number of speeches that include the keyword) and relevance based on our judgement. As shown in the table, for the first iteration the resulting keyword is "Green Finance", which we then add to our dictionary, expanding it to two keywords, and we repeat the process. This continues until we can no longer find additional keywords that are useful. At that point the automated dictionary, which consists of the keywords: "Climate Change", "Green Finance", "Climate-related Risk", "Paris Agreement", "Climate Policy", "Climate Risk", "Low-carbon Economy", "Carbon Emission", "Green Bond", is complete. The final two rows of Panel B of Table 2 show that a dictionary comprised of these nine key words identifies 400 (93%) of the 427 high score speeches leaving 27 high score speeches unidentified.

The final step is to use the automated dictionary to refine our initial set of speeches. We do this using a rule such that a speech is included in the final set of climate-related speeches if it contains any keyword from the dictionary in at least two separate sentences within the speech. The last row of Table 2 shows this refinement reduces the 2,337 initially identified speeches down to 555 speeches that constitute our final set of climate-related speeches.

3.3 Validity Checks

As discussed in Grimmer and Stewart (2013) and Gentzkow, Kelly and Taddy (2019), our approach requires a careful validity check to ensure that the speeches identified are indeed meaningfully climate-related.

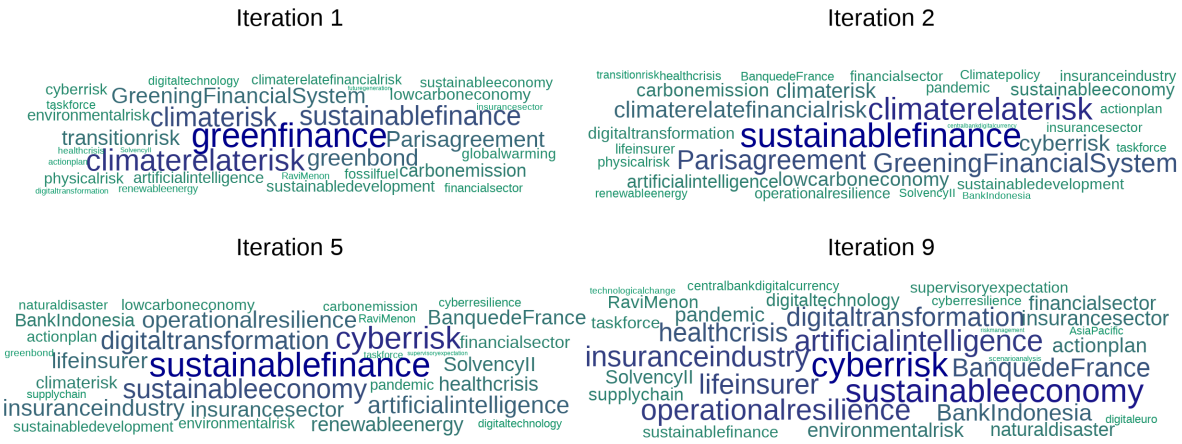
Our validity checks take two forms. We start by examining speech score summary statistics and word clouds. Comparing pre-refinement speeches (Panel A of Table 2) to post-refinement speeches (Panel C), the range of scores remains unchanged but the average in the post-refinement set is higher (0.98 compared to 0.34). This suggests the refinement is effective at separating out low score speeches that are meaningfully related to climate change from those that are not.

The information in Panel B of Table 2 offers details on how the refinement achieves this separation. For example, the table shows that in the first iteration the single keyword "climate change" is sufficient to identify 373 of the 427 highest score speeches. Of the 54 that remain unidentified, the average score of 0.77 is relatively low but the maximum remains quite high indicating that there remain some meaningfully climate-related speeches within this subset. The word cloud in the upper left of Figure 2 confirms that climate-related topics do indeed feature prominently in this subset of unidentified speeches.[18] Our methodology addresses this by adding an additional keyword chosen from this set (what we call the keyword exploration set) and then rerunning the identification based on this expanded dictionary. We continue doing this in subsequent iterations until we can no longer identify a useful keyword to add to the dictionary. Panel B of Table 2 shows that both the average and the maximum score for the keyword identification set are decreasing at

[18] In word clouds, size represents a frequency of the word in a set of speeches. Rather than a simple count of the number of times that the word appears in a text, text analysis practices suggest that putting more weight on meaningful words makes them more useful to interpret. Following such practices, Figure 2 uses a document frequency (i.e., the number of speeches that include a word) that is multiplied by the corresponding word score to put more weights on important words for detecting climate-related speeches. Figure 3 and thereafter use TF-IDF (term frequency-inverse document frequency), which is widely used in practice. TD-IDF adjusts a simple frequency by putting less weights on words that commonly appear across the entire set of speeches.

each iteration as it becomes increasingly difficult to identify additional keywords. As can be seen in the bottom right panel of Figure 2 the most frequent words used in the keyword identification set at the final iteration have little to do with climate change.

Figure 2: Word clouds of speeches used for keyword exploration



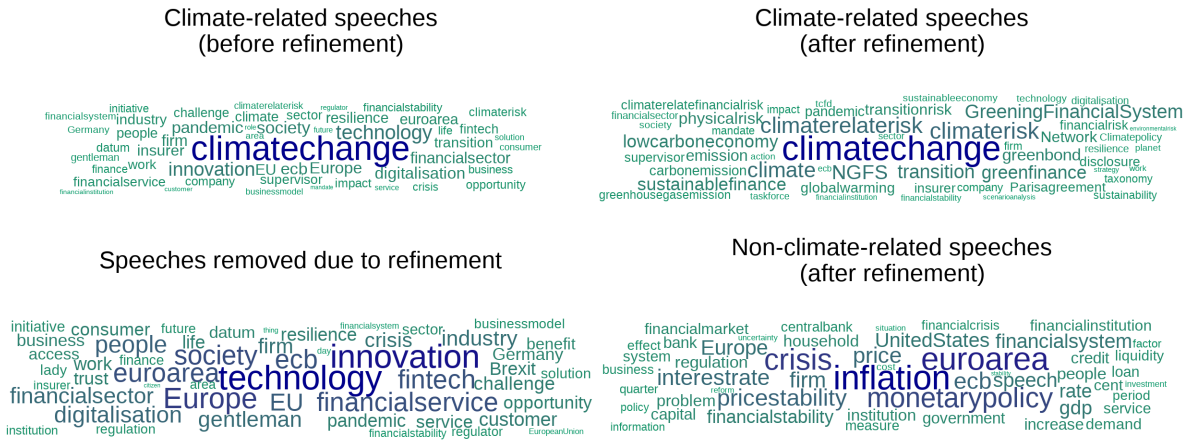
Source: Author's calculations.

After applying our completed dictionary to the set of pre-refinement speeches, the post-refinement set includes 367 of the 427 total high score speeches used for the keyword exploration (i.e., the refinement filters out 60 speeches as not meaningfully climate related). Of those, 27 (with an average speech score of 0.56) are removed because they do not contain any of the keywords and an additional 33 (with an average speech score of 0.66) are filtered because they do not contain at least one key word in two separate sentences. The refinement also adds an additional 188 speeches that have low scores (average speech score of 0.28) but nonetheless did satisfy the dictionary-based refinement criteria. This is an indication that the refinement adds value to the identification process beyond a simple high score cutoff. Figure 3 shows word clouds for climate-related speeches before refinement (top left) and after refinement (top right). The most frequent words in the post-refinement set are more narrowly related to climate-relevant topics compared to the pre-refinement set. The lower left panel shows a word cloud for those $1,782$ speeches filtered out of the pre-refinement set. These speeches tend to focus on topics like technology, financial sector innovation, and Brexit, for example. Finally, the lower right panel shows a word cloud for all speeches that are not climate-related. They tend to focus on standard central bank topics such as inflation and monetary policy.

In addition to speech statistics and word clouds, we also hand validate a sampling of both climate-related and non-climate related speeches. Hand validation is time-consuming, so we concentrate on four subsets of speeches that best define the identification boundary. We start with the 27 speeches filtered out of the set of highest score speeches because they do not contain any keyword from the dictionary. These speeches focus on topics like cyber risk, social responsibility, or the insurance industry (see the bottom right panel of Figure

2).[19] It is common for climate change to be mentioned along side these topics, and indeed even in the same sentence, and this drives up the speech score. We think it is warranted to remove them from the final set of climate-related speeches.

Figure 3: Word clouds for climate-related speeches, before and after refinement



Source: Author's calculations.

Next, we turn to the 33 high score speeches that were excluded at the final refinement step (speeches that contain at least one keyword from the dictionary, but not in at least two sentences). These speeches cover a variety of topics that only lightly touch on climate issues.[20] For example, some discuss the insurance sector and tangentially mention climate as a potential issue of concern. Other speeches focus on sustainable finance and mention climate issues only in passing. Under a different identification scheme some of these speeches might have been included in the final set, but in general they tend to treat climate-related topics only lightly, so it seems reasonable to exclude them.

Focusing on the boundary between climate-related and non-climate-related speeches, the three climate-related speeches with the lowest speech scores (i.e., the last three in) all discuss climate issues to some extent but in no sense is it the main theme of the speech. For example, Nabiullina (2021) "Speech at Association of Russian Banks" (web link), which scored a 0.0002, touches on climate change only to the extent that it is an issue that banking system faces. Olsen (2021) "Monetary policy strategy - from mandate to decisions" (web link) scored a 0.02 and only briefly touches on climate in the context of the central bank mandate. Finally, Gang (2021) "Hong Kong's positioning and prospect as an international financial centre" (web link) scored a 0.03 and discusses green finance as a particular strength of Hong Kong's financial markets. On the

[19] Examples include: Hendar (2015) "Increasing cooperation between Indonesia's central bank and state police" (web link); Lautenschlager (2017) "Cyber resilience - a banking supervisor's view", (web link); and Waas (2014) "Handling alleged payment system and currency exchange crime." (web link).

[20] Examples include: Diokno (2021) "Sustainability in investing" (web link); Elderson (2018) "Let the future of finance be that of financing the future" (web link); Lane (2016) "Dual perspectives on the insurance sector – consumer protection and financial stability" (web link).

other side of the cutoff, all of the highest scoring non-climate-related speeches were all excluded during the speech refinement stage, so they have been already reviewed above .

Finally, we examined 11 speeches that do not satisfy the initial criteria of having a speech score greater than zero, but do satisfy the refinement criteria of having a keyword in at least two sentences. These negative score speeches tend to focus on monetary policy and financial market developments.[21] Climate-related words are used largely in the context of concerns about commodity prices, for example, or through discussion of how enhancement of green finance might be favorable to financial market development. In principle, these types of speeches are candidates for inclusion. However, after reviewing each of them, our judgment is that the treatment of climate change is only cursory (which is what leads to the negative score) and for that reason we choose not to include them in our final set.

Some caveats are worth noting. First, selection of the seed word itself, as well as the speech score thresholds, will affect the final results. For example, changing the seed word to something other than "climate change" affects the distribution of speech scores and this matters for the final set of speeches. Second, we chose a threshold of 0 for identifying pre-refinement speeches. Raising this threshold would lead to fewer pre-refinement speeches and that would also affect the final set. By the same token, lowering the threshold should lead to more pre-refinement speeches, but this is less worrisome because the refinement stage would likely filter many of these additional speeches out. The third caveat is that we focused the keyword identification set on the pre-refinement speeches that had a speech scores greater than two standard deviations over the mean. Raising (or lowering) this threshold will decrease (or increase) the size of the keyword exploration set and that, in turn, matters for how the dictionary is constructed. A fourth caveat is that the selection of keywords, though guided by some computational tools, is ultimately based on judgment. Different keywords might lead to a different set of identified speeches. Given these caveats, some degree of hand validation seems inevitable.[22]

Finally, there are instances where the identification methodology is not perfect. For example, Haldane (2010) "The $100 billion question" (web link) is identified by our methodology as a climate-related speech but a close read reveals that climate change is only referred to in the speech as an example of a negative externality, which is then used to motivate why central banks should take action against systemic financial risk. The speech is not about central banking and climate change *per se*. This sort of mis-identification seems unavoidable, although it is comforting that the score assigned to this speech was very low at 0.081 (among the bottom twenty speeches included).

3.4 Summary Statistics

Summary statistics are presented in Table 3. Roughly one half of all central banks (50 out of 108 total in the sample, or 46.2%) have given at least one speech on climate change amounting to just over 3% of

[21] Examples include: Trichet (2008) "Monetary policy in challenging times" (web link); Yue (2021) "Hong Kong's positioning and prospect as an international financial centre" (web link); Macklem (2021) "The long and short of it - a balanced vision for the international monetary and financial system" (web link)

[22] We explored the sensitivity of our final set of climate-related speeches to these parameters. The most sensitive are the initial seed word and the threshold used for identifying the pre-refinement speech set. In contrast, the set of high score speeches used for the refinement stage is robust across the choice of parameters and, as a result, the identified keywords are relatively insensitive.

all speeches in the dataset. The average speech score is 0.98. Central banks in advanced economies are more active compared to emerging markets. Nearly 80% of all advanced economy central banks (29 out of 37 total) have given at least one climate-related speech which account for 3.8% of all speeches given by advanced economy central banks. In contrast, only about 30% of emerging market central banks (21 out of 71 total) have given at least one climate-related speech and amounting to around 1.5% of all speeches given. The average speech score of advanced economy speeches is 0.99 and, while lower for emerging markets at 0.90, the difference is not statistically significant.

Table 3: Summary statistics, Climate-related speeches

	# of Central Banks	Percent of Central Banks	# of Climate-related Speeches	Percent of Total Speeches	Average Speech Score
Total	**50**	**46.3%**	**555**	**3.2%**	**0.98**
Advanced Economy	29	78.4%	462	3.8%	0.99
Emerging Market Economy	21	29.6%	93	1.7%	0.90

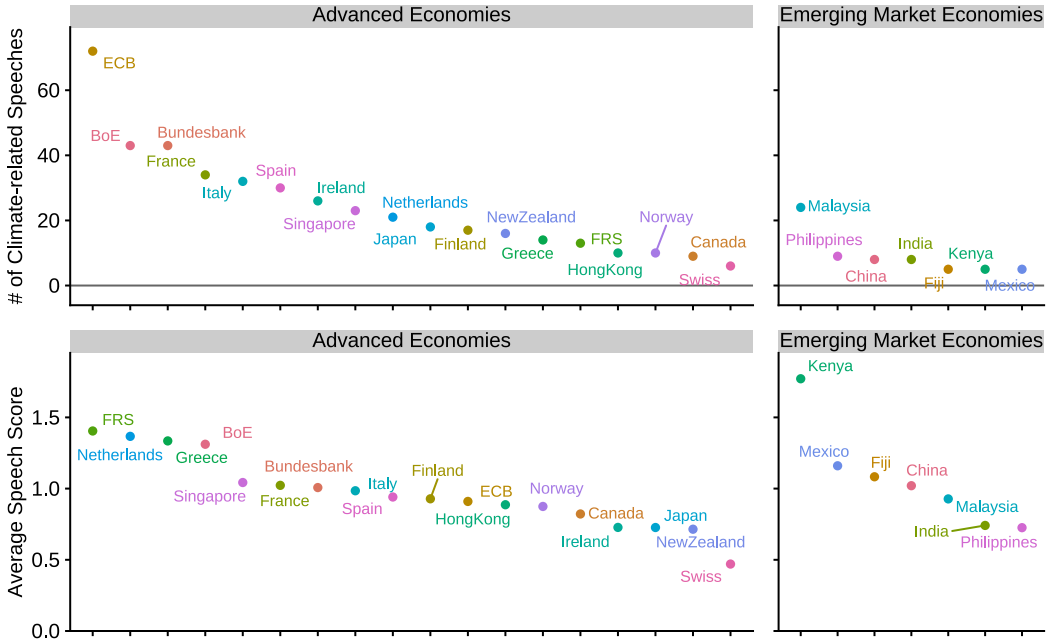
Source: Author's calculations.

The cumulative number of climate-related speeches given by each central bank over the entire sample period, conditional on giving at least five climate-related speeches, is shown in the top two panels of Figure 4. The top left panel shows the five most active advanced economy central banks are the ECB, the Bank of England, the Deutsche Bundesbank, the Bank of France, and Bank of Italy, each of which have given over thirty speeches related to climate change.[23]

The top right panel shows the most active emerging market central banks are the central banks of Malaysia, the Philippines, China, India, and Fiji. The bottom two panels show the same information for the average speech scores. Amongst advanced economies, the Federal Reserve, the Netherlands Bank, and the Bank of Greece have the three highest average speech scores despite having given a relatively low number of climate-related speeches. A similar dynamic exists amongst the emerging market economies as the Central Bank of Kenya and the Central Bank of the Phillipines rank highly on average scores across a relatively low number of total speeches.

[23]It is worth noting that the ECB identifies 46 climate-related speeches on its website (web link) and the Bank of Japan identifies 10 (web link). For comparison, our methodology identifies a wider set of climate-related speeches for both central banks, with 72 identified for the ECB and 18 identified for the Bank of Japan. Taking into account that the ECB and the Bank of Japan both list one climate-related speech on their respective websites that are not reported to the BIS, and therefore do not show up in our dataset, we identify 90 percent of the speeches reported by the ECB (40 of 45 speeches) and 100 percent of the speeches reported by the Bank of Japan (9 of 9).

Figure 4: Total number of climate-related speeches and average speech score by central bank, 1997-2021



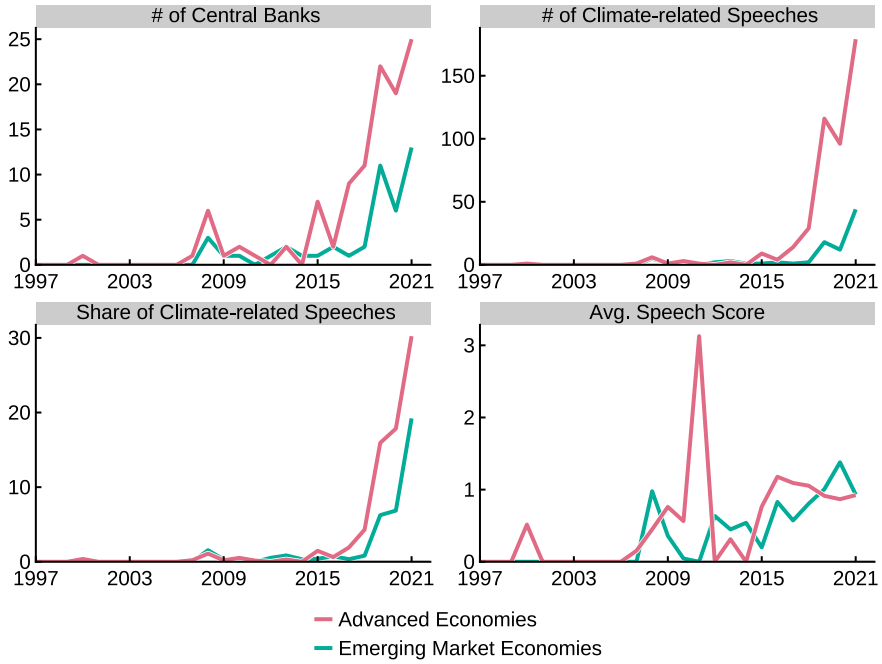
Notes: Central banks with less than five climate-related speeches are dropped from this figure.
Source: Author's calculations.

Figure 5 shows how communication about climate change has evolved over time. By all accounts, it has expanded sharply over the past five years. More central banks are speaking about climate and they are doing it with increasing frequency. The top left panel shows the number of central banks giving climate-related speeches has increased with a notable jump following the 2015 Paris Agreement.[24] The top right panel shows an even sharper increase in the number of speeches given each year. Over the past five years, the share of climate-related speeches (lower left panel) has shot up, rising from under 5 percent in 2017 to 20% of speeches given by emerging market central banks and more than 30% for advanced economies. Finally, the bottom right panel shows the the average speech score, which is a proxy for the extent to which climate-related topics are covered within a given speech (i.e., the intensive margin), has also increased steadily.[25]

[24]In April 2015, G20 Finance Ministers and Central Bank Governors asked the Financial Stability Board (FSB) "to convene public- and private- sector participants to review how the financial sector can take account of climate-related issues" (Financial Stability Board 2015).

[25]The spike in the average speech score for advanced economy central banks in 2011 is entirely driven by a single speech with a very high score of 3.13.

Figure 5: Climate-related speeches over time, 1997-2021



Source: Author's calculations.

Identifying the *most relevant speeches* in each year over the past twenty years offers another perspective on the evolution of climate-related speeches over time. Table 4 shows "Environmental issues and their implications for financial institutions in Hong Kong", given by the Hong Kong Monetary Authority (HKMA) was not only the most relavant climate-related speech given in 2000, but also the first climate-related speech identified overall in our set. Following this early contribution, there was a dearth of climate-related speeches until the late 2000s, at which point the issue seems to have resurfaced, perhaps owing to the Nobel Peace Prize being awarded to the Intergovernmental Panel on Climate Change and Al Gore Jr in 2007. From 2007 to 2014 the speech score for the most relevant climate-related speeches averaged just under 1.20, but this average is supported by two very high scoring speeches given by representatives of Bank Indonesia and the Bank of Greece in 2008 and 2011, respectively. Removing these two speeches pushes the average score down to a more modest 0.61, suggesting that while central banks were talking about climate in this early period they were quite limited in what they had to say. This changed notably following Mark Carney's 2015 speech on "Breaking the Tragedy of the Horizon: Climate Change and Financial Stability". Speeches that followed began to address climate topics more extensively with the average speech score for the most relevant climate-related speech in a given year rising to 2.81 over the period 2015 to 2021.

Table 4: Most relevant climate-related speeches by year, 1997-2021

Year	Central Bank	Speaker and Title	Date	Climate Speech Score	Total # of Climate-related Speeches
2000	Hong Kong Monetary Authority	David Carse: Environmental issues and their implications for financial institutions in Hong Kong	2000-11-29	0.52	1
2007	Monetary Authority of Singapore	Goh Chok Tong: Staying ahead of the Asian curve	2007-11-01	0.15	1
2008	Bank Indonesia	Boediono: Macroeconomic impact of climate change - opportunities and challenges	2008-08-02	2.76	11
2009	Bank of Italy	Mario Draghi: The financial crisis - impact and responses	2009-04-26	0.76	2
2010	Bank of Italy	Anna Maria Tarantola: Women nurturing sustainable development	2010-10-22	1.05	4
2011	Bank of Greece	George A Provopoulos: The impact of climate change in Greece	2011-06-01	3.13	1
2012	Central Bank of Malaysia	Muhammad bin Ibrahim: Role and opportunities of the financial system in supporting green technology	2012-10-02	0.68	2
2013	Central Bank of Trinidad and Tobago	Jwala Rambarran: Generating more inclusive economic growth through science and technology	2013-06-05	0.48	5
2014	Reserve Bank of India	G Padmanabhan: Corporate sustainability a panacea for growth - values, convictions and actions	2014-10-17	0.54	1
2015	Bank of England	Mark Carney: Breaking the tragedy of the horizon - climate change and financial stability	2015-09-29	2.25	10
2016	Bank of England	Mark Carney: Remarks on the launch of the Recommendations of the Task Force on Climate-related Financial Disclosures	2016-12-14	2.26	6
2017	Bank of Greece	Yannis Stournaras: Climate change - challenges, risks and opportunities	2017-06-30	3.70	15
2018	Bank of England	Mark Carney: A transition in thinking and action	2018-04-06	2.91	31
2019	Central Bank of Kenya	Patrick Njoroge: The importance of green finance guidelines as Nairobi seeks to become a global hub	2019-02-20	2.84	134
2020	Reserve Bank of New Zealand	Adrian Orr: Progressing climate action by driving transformational change	2020-10-28	2.91	108
2021	Bank of Japan	Haruhiko Kuroda: Addressing climate-related financial risks – from a central bank's perspective	2021-03-25	2.77	223

Source: Author's calculations.

All told, central bank communication about climate change has expanded rapidly, both at the extensive margin (as captured by the number of speeches focusing on climate change and the number of central banks giving these speeches) and at the intensive margin (as captured by the average speech score).

4 What do Central Banks Talk About with Regard to Climate?

We summarize some topics that central banks address in their speeches about climate change, starting with financial stability and macroprudential policy before turning to a broader set of topics.

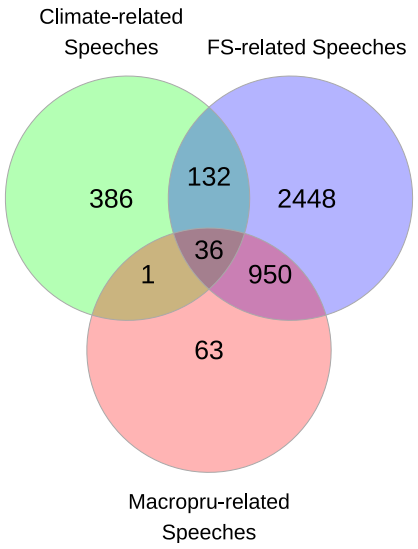
4.1 Climate Change, Financial Stability, and Macroprudential Policy

We are particularly interested in how central banks discuss the use of macroprudential tools to address financial stability risks associated with climate change. To focus on the overlap between these three topics we applied the same methodology as described in Section 3.2 to identify financial stability-related speeches and speeches related to macroprudential policy.

Starting with the seed word, "financial stability", we create a score for every speech and use it to identify an unrefined set of financial stability-related speeches. This set is then refined using high score speeches to create a "financial stability" dictionary, which consists of the following keywords: "financial stability"; "systemic risk"; "macroprudential policy"; "resolution regime"; "macroprudential instrument"; "countercyclical capital buffer"; and "macroprudential perspective". We apply this dictionary using the same identification rule from Section 3.2 (at least one keyword in two separate sentences within the speech) to identify 3,566 speeches (just over 20% of all speeches) that focus on the topic of financial stability. Similarly, we use the seed word "macroprudential policy" to create a dictionary consisting of the keywords: "macroprudential policy"; "systemic risk"; "macroprudential regulation"; "macroprudential instrument"; "financial vulnerability"; "countercyclical capital buffer"; "macroprudential measure"; "macroprudential supervision"; and "macroprudential analysis" and use it to identify 1,050 speeches (6% of all speeches) focusing on macroprudential policy.[26]

After classifying speeches into those that are climate-related, financial stability-related, and macroprudential policy-related, we assess the extent of overlap by looking for speeches at the intersection of the three topics. Figure 6 shows that of our 555 total climate-related speeches, a little under one-third (168, or 30.0%) also touch on financial stability, but only a small handful (37, or 6.7%) address macroprudential policy. In comparison, over one quarter of all financial-stability related speeches (986, or 27.7%) also touch on macroprudential policy issues. That said, much of the focus in the remainder of this section is on the 36 speeches at the intersection of all three topics.

Figure 6: Climate-related, financial stability-related, and macroprudential policy-related speeches



Source: Author's calculations.

[26]The "financial stability" and "macroprudential policy" dictionaries share some of the same keywords, so overlap between the two sets of speeches is to be expected. That said, the speech scores, which are used to create the unrefined speech sets to which the dictionaries are applied, are based on different seed words. As a result, any overlap introduced from common keywords would only be introduced in the refinement stage.

To better understand this subset of speeches Table 5 shows average speech scores across the three topics for different speech subsets. The top panel compares climate-related speeches to non-climate-related speeches. As expected, the average climate-related speech score is much higher for climate-related speeches relative to non-climate related speeches and the difference is statistically significant. It is also true that climate-related speeches have higher financial stability speech scores and higher macroprudential speech scores, although the difference is smaller in magnitude (albeit still statistically significant). In other words, the typical climate-related speech is more likely to address both financial stability- and macroprudential-related topics relative to the typical non-climate-related speech. The bottom panel focuses on the subset of speeches that address both financial stability and macroprudential policy issues. Climate-related speeches that touch on both topics tend to treat them more lightly relative to speeches that are not climate-related.

Table 5: Speech scores for different subsets of climate- and non-climate-related speeches

	Climate-related Speech Score	FS-related Speech Score	Macropru-related Speech Scoer
Climate-related speeches, (n=555)	0.98	0.15	-0.22
Non-climate-related speeches, (n=16,850)	-0.31	-0.03	-0.32
Difference	**1.28**	**0.18**	**0.10**
p-value	**0.000**	**0.000**	**0.000**
Climate-FS-Macropru, (n=36)	0.51	0.39	0.23
Non-climate-FS-Macropru, (n=950)	-0.21	0.48	0.35
Difference	**0.72**	**-0.09**	**-0.12**
p-value	**0.000**	**0.003**	**0.000**

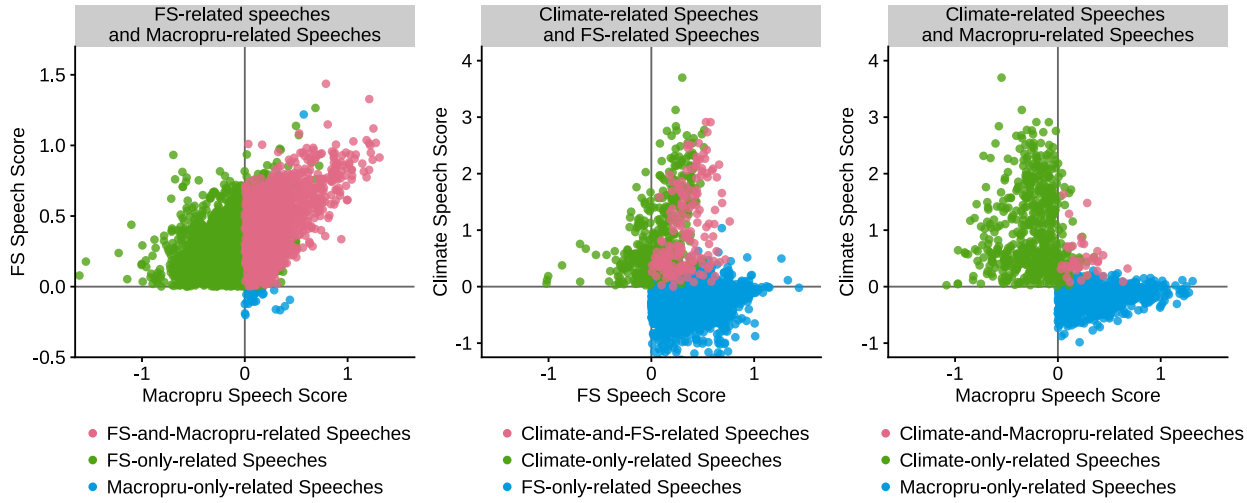
Source: Author's calculations.

Figure 7 compares speech scores for different subsets of speeches in a series of scatter plots. The left panel compares the 3,566 financial stability- and 1,050 macroprudential policy-related speeches. Those focusing exclusively on financial stability or exclusively on macroprudential policy are depicted by the green and blue dots, respectively. Speeches at the intersection of the two topics are depicted by the red dots. The relationship between the financial stability and macroprudential speech scores in all three subsets is positive (the green, blue, and red dots are all upward sloping), suggesting that the two topics are often discussed closely together. The middle panel shows compares our 555 climate-related speeches to financial stability-related speeches, the majority of which are not related to climate change (as depicted by the blue dots). For those that either focus exclusively on climate (the green dots) or touch on both topics in the same speech (the red dots) there is a positive correlation between the speech scores suggests that financial stability is often discussed in the context of climate change. The final panel on the right compare climate-related speeches to macroprudential policy-related speeches and in doing so shows an important dichotomy. Climate-related speeches (the green dots hug the y-axis) rarely address macroprudential topics and vice versa (the blue dots hug the x-axis). In the rare case the two topics overlap (37 speeches total), the relationship between the climate speech score and the macropruendtial policy speech score is weak.

To summarize, financial stability and macroprudential policy topics do tend to show up more frequently in climate-related speeches relative to speeches that are not related to climate change. However, when we focus on the subset of speeches where we might expect to find the most extensive discussion of these topics

in the context of climate change, we find that central banks tend to treat both topics only lightly.[27]

Figure 7: Topic relevance in climate-, financial stability- and macroprudential policy-related speeches



Source: Author's calculations.

Digging a little deeper, we explore our set of climate-related speeches to identify any mention of specific policy tools possibly associated with climate change. To do this, we collected a total of 1,498 climate- or green-related keywords (i.e., "Climate XXX" and "Green XXX") found in our set of climate-related speeches and judgmentally selected 65 relevant policy tools that show up in this set of words.[28] These 65 policy tool keywords were then grouped into six different categories: climate disclosure, climate risk management, green taxonomy, climate research, climate scenario analysis/stress testing, and green monetary policy/capital allocation.

With these dictionaries in hand, we then identify 183 speeches that address climate-related topics and also contain some mention of any of these policy tool keywords. Table 6 shows the distribution across the six categories. The most frequent references to policy tools tend to be microprudential in nature. For example, over twenty percent of all climate-related speeches (114 out of 555 total) contain some keyword associated with climate disclosures, meaning either voluntary or mandatory reporting of climate risk exposure which might allow central banks, supervisors, and private market participants to better understand climate-related

[27]Two examples of recent speeches that touch on both topics, but only lightly are Lagarde (2021), "Macroprudential policy in Europe – the future depends on what we do today" (web link)) *"Effective climate policies would also benefit the financial sector. But macroprudential policymakers have a part to play, too, in identifying and mitigating the financial aspects of climate-related risks."* and Lane (2019) "Climate change and the Irish financial system" (web link) *"This calls for ongoing monitoring of climate risks, together with the development of climate-driven scenario analyses and stress tests. By extension, the results of such analyses may call for the appropriate macroprudential policies to mitigate these risks."* This light treatment stands out given the typically tight relationship between financial stability and macroprudential policy observed in non-climate-related speeches.

[28]Most of 1,498 climate- or green-related keywords, "climate crisis" and "green investment" for example, are not obviously related to climate policy tools. In addition, we also remove words, such as "climate policy instrument" and "green finance policy" that do not indicate specific tools. See Appendix C for a list of all 65 keywords of specific policy tools and their classifications into 6 categories.

Table 6: Keywords for identifying specific climate policy tools mentioned in climate-related speeches

Category	Number of speeches	Average Climate Speech Score	Average FS Speech Score	Average Macropru Speech Score
All Climate-related Speeches	555	0.98	0.14	-0.22
Any Climate Policy Tools	183	1.48	0.27	-0.19
Climate Disclosure	114	1.60	0.30	-0.17
Climate Risk Management	48	1.51	0.28	-0.25
Green Taxonomy	26	1.58	0.20	-0.27
Climate Research	12	1.49	0.31	-0.13
Climate Scenario Analysis / Stress Test	74	1.65	0.34	-0.16
Green Monetary Policy / Capital Allocation	12	1.33	0.17	-0.14

Source: Author's calculations.

financial risks. An additional 10% (48 speeches) touch on climate risk management. Typically, the language in these speeches is geared toward identifying and monitoring to get a better understanding of both macro and/or microprudential implications of climate risk.[29] Green taxonomy accounts for 5% (26 speeches) of identified speeches. The discussion typically focuses on developing a common set of definitions regarding the environmental profile of assets and financial market participants and is closely associated with green/sustainable finance.[30] Climate research comes up in 2% (12 speeches) of identified speeches likely reflecting that central banks lack sufficient understanding of climate risk and need to better understand those risks before taking policy action.[31] Climate scenario analysis/stress testing is mentioned in roughly 15% of all climate-related speeches (74 speeches). Many discuss the usefulness of scenario analysis from a microprudential perspective, for example in the context of risk assessment.[32] That said, a handful of speeches do touch on top down stress testing as a means of assessing the systemic implications of climate risk with an eye toward guiding macroprudential policy.[33]

[29] For example, Stiroh (2020) "Climate change and risk management in bank supervision" (web link), *"...supervisors can focus on identifying and managing risks, both microprudential and macroprudential, that emerge along a transition path to a more sustainable economy"*, and Elderson (2021) "Overcoming the tragedy of the horizon" (web link), *"Getting banks to develop action plans to comply with the expectations that the ECB set out in its guide on CE risks was the first step in getting them to assess and develop their risk management capabilities."*

[30] Menon (2021) "Being the change we want to see - a sustainable future" (web link) *"Developing a clear taxonomy for transition activities is especially relevant for Asia. Asia needs to sustain economic and social development while shifting to a lower carbon future. A taxonomy that includes both green and transition activities can support a progressive shift to greater sustainability."*; Elderson (2018) "Let's dance" (web link) *"We should remove all unnecessary obstacles to this transition. And assist the sector in creating common definitions and standards. As well as provide the necessary guidance. The development of a sustainable taxonomy is a good example of this."*

[31] Stournaras (2018) "Climate change - threats, challenges, solutions for Greece" (web link) *"Greece, along with other small countries in the climate-sensitive Mediterranean region, is expected to incur adverse effects from climate change. Acknowledging this fact, the Bank of Greece has been one of the first central banks worldwide to actively engage in the issue of climate change and invest significantly in climate research."*

[32] Breeden (2019) "Avoiding the storm - climate change and the financial system" (web link) *"Measuring these future risks from climate change to the economy and to the financial system is a complex task. A myriad of possible climate pathways – with different physical and transition effects – need to be translated into economic outcomes and financial risks looking ahead over many decades. To simplify that challenge, we need to focus not on what will happen but what might happen. To do that we can use scenario analysis – data driven narratives that help anchor our assessments of risk."*

[33] For example, de Guindos (2019) "Implications of the transition to a low-carbon economy for the euro area financial system" (web link) *"The pilot test framework will be macroprudential in nature, and allow us to analyse the system-wide materiality of*

Speeches that address green monetary policy/capital allocation make up only 2% (12 speeches) of all climate-related speeches. These speeches stand out because they reference a number of policy tools that we tend to think of as traditionally macroprudential in nature. The tools mentioned can be split into two groups. First, some speeches discuss green monetary policy in the form of quantitative easing or tailoring central bank asset purchases to the environmental profile of those assets.[34] At least one speech raises the possibility of allowing for favor green collateral in monetary policy credit operations, but raises this possibility with a good deal of skepticism.[35] The second group of climate-related tools operate through the banking sector and includes risk weighting "discounts" for green assets and "penalizing factors" for brown assets as well as capital requirements tailored to carbon intensive exposures.[36] Regardless of whether it is green monetary policy or capital requirements, these tools tend to be discussed more in the context of supporting the transition to a net zero carbon world by supporting green finance as opposed to tools directed to addressing climate-related financial stability risks. To this end, at least some discussion centers around the question of how effective central banks can be in achieving climate-related objectives and highlights the possibility of unintended consequences, including disintermediation and risk-shifting.[37]

All told, the evidence suggests that central banks have very little to say at this point about specific macroprudential policy tools in the context of climate-related financial stability. Most discussion of policy tools or actions tends to be more focused on microprudential policy with a particular emphasis on mandatory disclosure and/or climate scenario analysis. In instances where the possibility of systemic risk does feature more prominently, the discussion of available tools—such as stress testing that goes outside of the banking sector—still blurs the lines between micro and macroprudential policy.

transition risks for banks' solvency, along with their lending capacity and the implications for the overall economy."; Lane (2019) "Climate change and the Irish financial system" (web link) *"This calls for ongoing monitoring of climate risks, together with the development of climate-driven scenario analyses and stress tests. By extension, the results of such analyses may call for the appropriate macroprudential policies to mitigate these risks."*; Carney (2019) "TCFD: strengthening the foundations of sustainable finance" (web link), *"Supervisors of financial sector firms will also need to consider which metrics are most useful for different levels of assessment: - Microprudential, to assess how individual firms are managing climate-related risks - for example the impact of a physical or transition risk on a loan book. - Macroprudential, to consider how and whether individual exposures could scale up to systemic risk - Macroeconomic, to help understand how the financial system and economy interact in different climate transition scenarios."*

[34] Villeroy de Galhau (2021) "The role of central banks in the greening of the economy" (web link) and Mauderer (2019) "Central banks - a crisis manager for the climate?" (web link)

[35] Weidmann (2019) "Climate change and central banks" (web link)

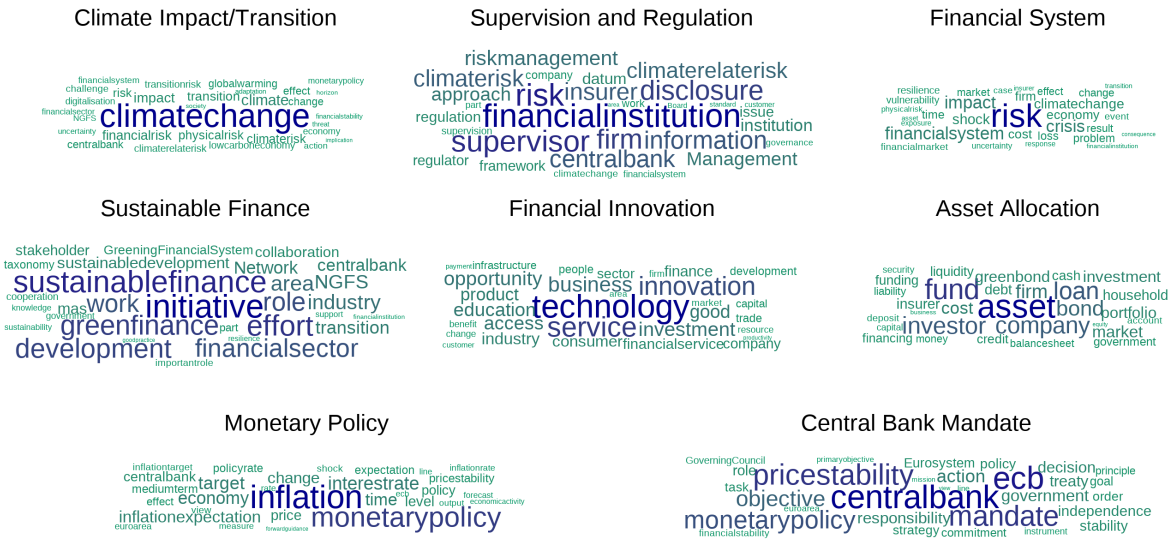
[36] Bailey (2021) "Tackling climate for real - the role of central banks" (web link), Matsen (2019) "Climate change, climate risks and Norges Bank" (web link)

[37] Weidmann (2019) "Climate change and central banks" (web link) and Diaz de Leon (2021) "Remarks - How can central bankers and supervisors support climate risks and green finance and manage risks?" (web link)

4.2 Other Topics in Climate-related Speeches

Central banks cover a wide variety of climate-related topics that go beyond financial stability and/or macroprudential policy. Focusing on the 386 climate-related speeches shown in Figure 6 that have no overlap with financial stability or macroprudential policy, we use cluster analysis at the sentence level to identify some other topics that feature prominently.[38] The topics we identified are: Climate Impact/Transition; Supervision and Regulation; Financial System; Sustainable Finance; Financial Innovation; Asset Allocation; Monetary Policy; and Central Bank Mandate. Word clouds for each topic are presented in Figure 8 to give a better sense of the subject matter in each cluster.

Figure 8: Word clouds for climate-related topics identified via cluster analysis

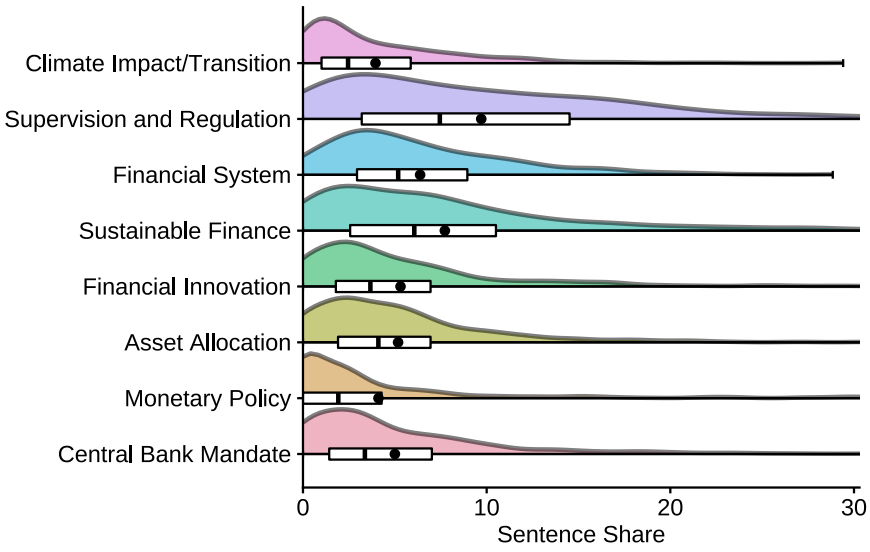


Source: Author's calculations.

Figure 9 shows the distribution of sentence topic shares in individual speeches (i.e., the number of sentences in a speech focusing on a given topic of interest expressed as a fraction of the total number of sentences in that speech) for the topics we identify. For each topic, the dot is the average sentence share across all speeches, the dash is the median, and the box represented the 25^{th} and 75^{th} percentile. Sentences shares are distributed relatively evenly across all eight topics, although some are more prevalent than others (for example, Sustainable Finance relative to Climate Impact/Transition) and some distributions have notably longer and fatter tails than others (for example, Supervision and Regulation relative to Monetary Policy).

[38] We apply k-means clustering method to all 43,372 sentences in 386 climate-related speeches which are represented by 300-dimensional vectors that are mapped using word embedding techniques (see Appendix B for a detailed description of our methodology). As discussed in Section 3.1, unsupervised topic models such as LDA could be alternative ways to discover unknown topics. LDA could provide similar clustering results to those demonstrated in section 4.2, but they were less interpretable and not robust in the sense that results were heavily depending on hyper parameters that are arbitrary set before estimation, sampling algorithms and ways of word pre-processing.

Figure 9: Sentence share distribution, by topic



Source: Author's calculations.

Table 7 shows correlations in sentences shares across topics. A positive correlation across two topic pairs suggests that both topics tend to show up together in the same speech whereas a negative correlation suggests the opposite. Additional details on the types of issues discussed in each topic are provided below, but the correlation table makes it clear that certain topics naturally tend to be discussed together. For example, sentences that touch on Climate Impact/Transition tend to show up together in the same speech with discussion of Supervision and Regulation and the Financial System. Monetary policy in the context of climate change tends to be discussed in close association with the central bank mandate. Some degree of correlation across topics is to be expected because the metrics are constructed at the level of an individual sentence within a speech and central bank speeches cover many topics.

Table 7: Correlation of sentence shares across topics

	Climate Impact /Transition	Supervision and Regulation	Financial System	Sustainable Finance	Financial Innovation	Asset Allocation	Monetary Policy	Central Bank Mandate
Climate Impact/Transition	1.00	0.22***	0.27***	0.04	−0.14**	−0.21***	−0.18***	0.03
Supervision and Regulation	.	1.00	0.35***	0.15**	−0.12*	0.08	−0.32***	−0.11*
Financial System	.	.	1.00	−0.23***	−0.21***	0.13**	−0.13*	-0.06
Sustainable Finance	.	.	.	1.00	0.18***	−0.15**	−0.39***	−0.29***
Financial Innovation	.	.	.	.	1.00	−0.03	−0.26***	−0.33***
Asset Allocation	.	.	.	.	.	1.00	−0.10*	−0.06
Monetary Policy	.	.	.	.	.	.	1.00	0.39***
Central Bank Mandate	.	.	.	.	.	.	.	1.00

Notes: Asterisks denote statistical significance, *** indicates p-value<0.001; ** indicates p-value<0.01; * indicates p-value<0.05.
Source: Author's calculations.

Climate Impact/Transition. Speeches with a high share of sentences in this category touch on the impact of climate change on the economy and the financial system. The long-term impact of climate change is often discussed in the context of a managed transition to a zero emissions global economy, which explains the positive correlation in sentence share with the Supervision and Regulation category.[39] Speeches also touch on using the leverage of the financial system to help to manage this transition, hence the positive correlation with the Financial System category. In terms of central bank actions, measurement, transparency, and additional research on the topic are common. In addition, there are strong calls for global cooperation in better understanding the economic and financial implications of climate change.

Supervision and Regulation. This topic focuses on risk management practices, for supervised institutions as well as for supervisors themselves, and the alignment of bank actions with supervisory expectations features prominently.[40] Some speeches step outside the banking sector to address risk management in the insurance industry and liability risk is discussed in this context. Potential policy actions include improved measurement, promoting transparency in reporting, and international cooperation in standard setting. In addition, scenario analysis focused on the resilience of individual financial institutions (as opposed to top-down climate stress testing from a systemic risk, financial stability perspective) is discussed. In addition to Climate Impact/Transition and Financial System, sentences related to Supervision and Regulation tend to also show up in speeches that address Sustainable Finance.

Financial System. The financial system is discussed in climate-related speeches in ways that go beyond financial stability. For example, it is raised in the context of a lack of understanding of risk, often with an emphasis on uncertainty.[41] The lack of a well-developed analytic framework feeds this lack of understanding and is a concern for central banks, regulators, and financial market participants alike and this point is frequently raised. Some speeches are careful to point out the green transition creates potential opportunities for investors. With regard to policy tools or actions, transparency, global cooperation, and more research on the topic come up frequently. Scenario analysis/stress testing is discussed in both a microprudential as well as a macroprudential context. In addition to Climate Impact/Transition and Supervision and Regulation, sentences related to Financial System tend to also show up in speeches that address Asset Allocation.

Sustainable Finance. Sustainable finance captures the idea that central banks and regulators play an central role in supporting the alignment of financial industry responses with national climate strategies and priorities.[42] The objective is to encourage the development of a sustainable financial system on the transition path to a low-carbon economy. Coordination between the private sector, various domestic government agencies, including financial regulators, and international bodies is important. Speeches with a high share of

[39]The three speeches with the highest sentence share in this category are: Stournaras (2017) "Climate change - challenges, risks and opportunities" (web link); Stournaras (2019) "Climate change - threats, challenges, solutions for Greece" (web link); Elderson (2021) "Forests and finance" (web link).

[40]Elderson (2021) "Overcoming the tragedy of the horizon" (web link); de Guindos (2019) "Speaking notes on climate-related risks" (web link); Jain (2021) "Building a more resilient financial system in India through governance improvements" (web link).

[41]Jain (2021) "Building a more resilient financial system in India through governance improvements" (web link); Poloz (2019) "Release of the Financial System Review" (web link); Breeden (2019) "Avoiding the storm - climate change and the financial system" (web link).

[42]Nor Shamsiah Mohd Yunus (2021) "Remarks - Green Swan 2021 Global Virtual Conference" (web link), Yue (2020) "Managing climate risks in Hong Kong" (web link), and Chew (2021) "Opening remarks - World Bank's Sustainable ExchangE Development Series (SEEDS)" (web link)

sentences related to Sustainable Finance also touch on Supervision and Regulation and Financial Innovation.

Financial Innovation. Climate-related speeches discuss financial innovation largely in the context of promoting a sustainable and inclusive financial system.[43] (Sustainable Finance is the only category that shows a positive correlation with Financial Innovation in Table 7.) Examples of topics discussed include the growth of green investment products, the role of fintech in promoting green investing, and the need for increased global emissions trading. At least one speech touches on the potential environmental impact of the high levels of energy consumption required in the crypto-asset market.

Asset allocation. Asset allocation, or management, is discussed in the context of market pricing of risk, the balance sheet structure of insurers, or the role of non-bank financial intermediaries in adapting to uncertain climate risk.[44] Some speeches discuss incorporating Environmental, Social, and Governance (ESG) factors in investment portfolios sometimes with an emphasis on potential investment opportunities arising from energy transition. Central banks also talk about the carbon footprint of their own activities, either the composition of the balance sheet or as it relates to the management of domestic pension funds.[45]

Central Bank Mandate. Many speeches touch on how climate may or may not fit into the primary mandate on price stability but in some cases they also touch on secondary mandates in relation to environmental or sustainable growth objectives.[46] The thought that ensuring an adequate carbon pricing system is a job for elected officials, not central banks, is something that comes up in a handful of speeches.

Monetary policy. Finally, speeches discuss monetary policy in at least two contexts: either through the direct effect of climate change on economic activity or through the possibility that climate change could lead to structural change in the transition to net zero.[47] Structural change, in turn, could have implications for productivity and the natural rate of interest. Some speeches are very skeptical about the suitability of monetary policy to address climate-related issues, while others note that central banks have already committed to incorporating climate change into current monetary policy frameworks.

4.3 Advanced versus Emerging Market Economies

Our review of climate-related topics revealed some important differences in how communication is handled in advanced economy central banks relative to their counterparts in emerging market economies.

Figure 10 shows distributions for the climate, financial stability, and macroprudential policy speech scores broken out across the two cohorts of banks. The climate speech score distributions (left panel) are broadly similar in that both are bi-modal. This suggests there are two types of climate-related speeches for both advanced economy and emerging market central banks, those that treat climate relatively lightly (the

[43] Perrazzelli (2021) "Launch of the G20 TechSprint on green finance and sustainable economy" (web link); Carney (2019) "A platform for innovation" (web link); Santiprabhob (2019) "Thailand 2025 - dealing with major trends" (web link).

[44] Gerken (2021) "Developments in the PRA's supervision of annuity providers" (web link); Gerken (2021) "The PRA's role in improving the processes that support insurers' investment" (web link); de Guindos (2020) "The euro area financial sector - opportunities and challenges" (web link)

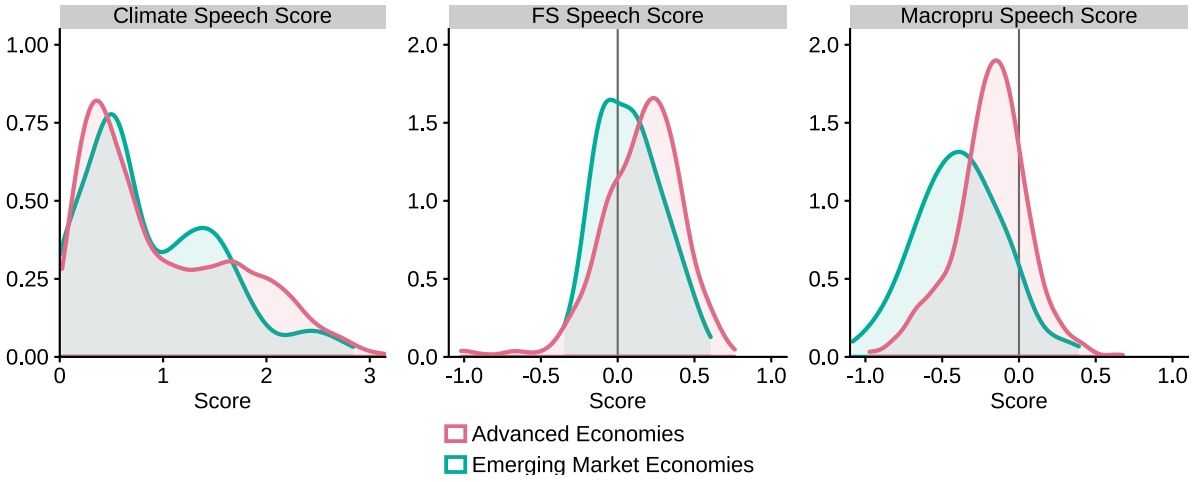
[45] See, for example, Breman (2020) "How the Sveriges Riksbank can contribute to climate policy" (web link) and Kuroda (2021) "The Bank of Japan's strategy on climate change."(web link)

[46] Lagarde (2021) "Press Conference" (web link); Scicluna (2021) "Price stability and beyond - understanding the impact of the ECB's Strategy Review" (web link); Schnabel (2021) "Societal responsibility and central bank independence" (web link).

[47] Some examples include Hernandez de Cos (2021) "The European Central Bank's new monetary policy strategy" (web link) and Macklem (2021) "Renewal of the Monetary Policy Framework" (web link)

first peak at lower score) or those that treat the topic more intensely (the second peak at the high score). One possible explanation for this is that as a speech topic, the prominence of climate change has grown over time. Early speeches touched on it only lightly, but as momentum in the central banking community has grown, the topic is now being treated more extensively. The evidence on the highest scoring climate speech per year shown in Table 4 supports this explanation as the speech scores rise over time. The climate-score distribution for advanced economies has a fatter right tail relative to the emerging market speeches, which supports the higher mean reported in Table 8 (although the two are not statistically different from one another). The middle and right panels shows that advanced economy central banks treat both financial stability and macroprudential policy more intensively then their emerging market counterparts. The difference in the average speech scores reported in Table 8 for each of these categories supports this conclusion. All told, the evidence suggests that central banks in advanced economies seem more willing to talk about both financial stability and macroprudential policy in the context of climate change relative to central banks in emerging market economies.

Figure 10: Speech score distribution, advanced economy and emerging market central banks



Source: Author's calculations.

Table 8: Average speech score, advanced economy and emerging market central banks

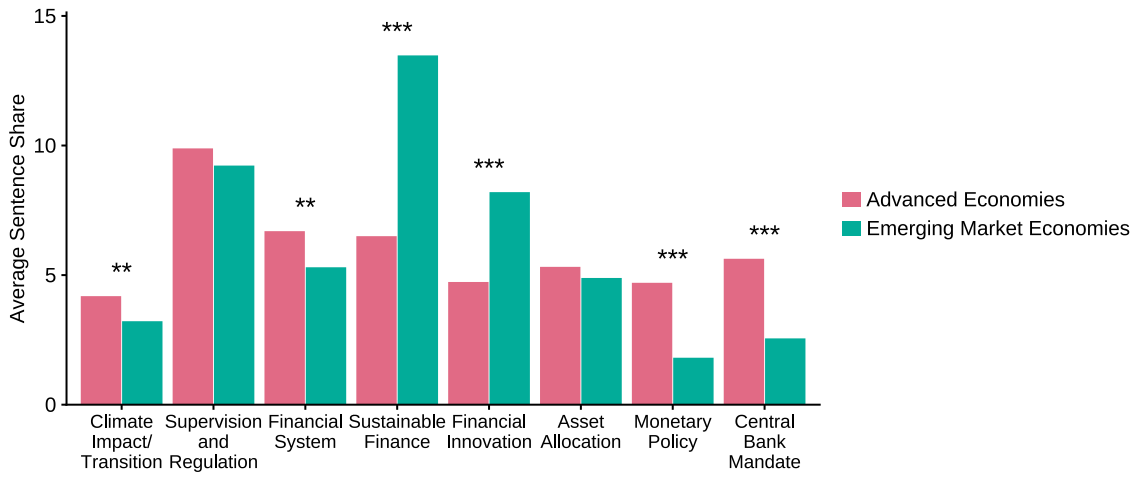
	Advanced Economies	Emerging Market Economies	**Difference**	**p-value**
Climate Speech Score	0.99	0.90	**0.09**	**0.27**
FS Speech Score	0.36	0.28	**0.08**	**0.00**
Macropru Speech Score	0.34	0.29	**0.05**	**0.02**

Source: Author's calculations.

The difference in topic treatment extends across beyond financial stability and macroprudential policy, Figure 11 shows the average sentence share for each of our six topics in non-financial stability, non-

macroprudential policy speeches broken out across the two subsets of central banks. Advanced economies have a higher average sentence share for Climate Impact/Transition (4.13 for advanced economies versus 3.16 for emerging market economies), Financial System (6.63 versus 5.24), Supervision and Regulation (9.83 versus 9.16), and Asset Allocation (5.56 versus 4.83). For the first two categories, the difference in means is statistically significant, but quantitatively small and for the second two categories the difference is not statistically different from zero. However, a more meaningful difference comes from the fact that advanced economies address Monetary Policy (4.64 versus 1.75 for a difference of 2.78) and the Central Bank Mandate (5.57 versus 2.50 for a difference of 3.07) notably more than emerging market central banks. At the same time, emerging market economies address Sustainable Finance (6.44 versus 13.42 for a difference of −6.97) and Financial Innovation (4.67 versus 8.14 for a difference of −3.47) much more extensively than central banks in advanced economies. An explanation for the difference in topic treatment likely comes back to the fact that many central banks in emerging market economies have wider ranging mandates that may include the central bank supporting sustainable development objectives.[48]

Figure 11: Average sentence share by topic, advanced economy and emerging market central banks



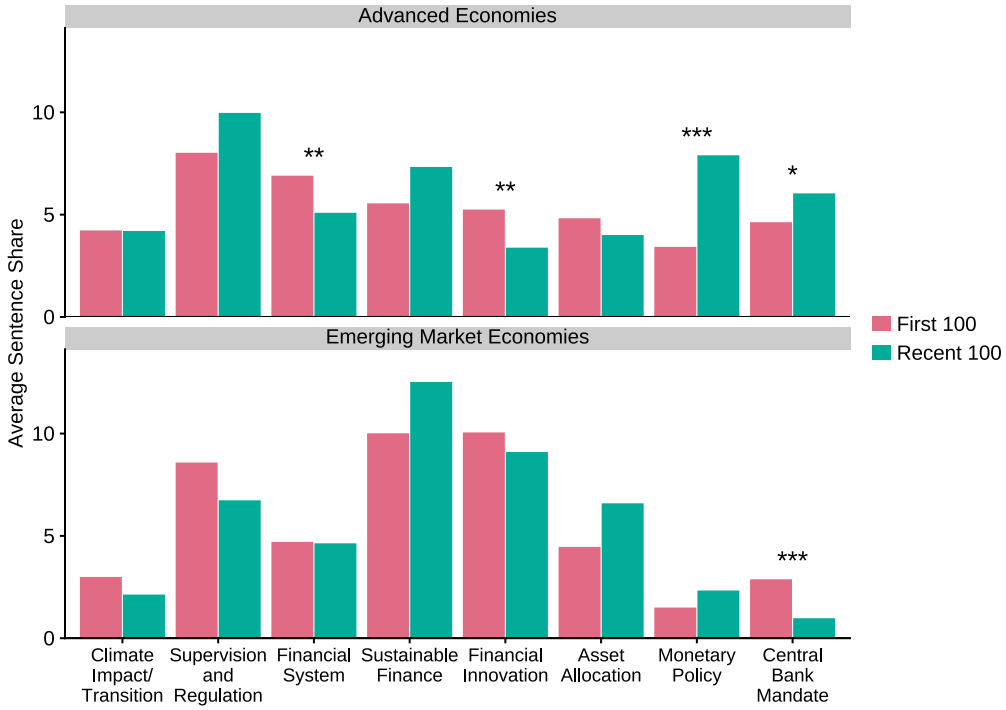
Notes: Asterisks denote statistical significance of difference in means between Advanced and Emerging Market Economies, *** indicates p-value<0.01; ** indicates p-value<0.05; * indicates p-value<0.10.
Source: Author's calculations.

This divergence in topic coverage across the two cohorts of banks is a development that has been evolving over time. To illustrate this, Figure 12 compares the average sentence share for each non-financial stability, non-macropruprudential policy topic for advanced economies (left panel) and emerging market economies (right panel). The red bars in each panel show the topic sentence share for the first 100 climate-related speeches (covering the period 2000 to March 2019) and the red bars show the same information for the most recent 100 speeches (covering July 2019 to 2021). Topic coverage for advanced economies has

[48] See Campiglio, et al. (2018) and Dikau and Volz (2021) for an extensive treatment of how climate fits into the mandates of various central banks.

moved away from issues related to the Financial System and Financial Innovation to concentrate more on climate in the context of Monetary Policy and the Central Bank Mandate. At the same time, topic coverage for emerging market economies as moved away from talking about Supervision and Regulation and the Central Bank Mandate toward Sustainable Finance and Asset Allocation.

Figure 12: Average sentence share by topic for first 100 speeches versus recent 100 speeches, advanced economy and emerging market central banks



Notes: Asterisks denote statistical significance of difference in means between Advanced and Emerging Market Economies, *** indicates p-value<0.01; ** indicates p-value<0.05; * indicates p-value<0.10.
Source: Author's calculations.

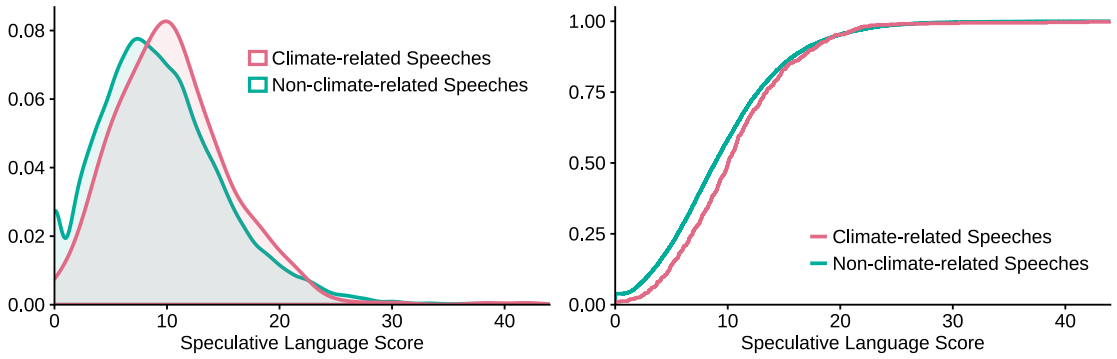
5 Ambiguity in Climate-related Language

In this section, we test statistically whether language used in climate-related speeches is materially different from that used in other speeches. The motivation is based, in part, on the finding from Section 4.1 that the link between financial stability and macroprudential policy for climate-related speeches is out of line with the link typically found in non-climate-related speeches. Moreover, our reading of the treatment of many topics addressed in Section 4.2 suggests a hesitancy of central banks to address climate-related issues with precise, definitive language.

Our focus is on the use of *speculative language*. The text analysis literature has a number of different ways to characterize speculative language, but we opt for a dictionary approach using keywords that com-

monly imply uncertainty: *may, might, can* and *could*.[49] Using this dictionary, we construct a speculative language speech score using a simple counting method. In this case, we count the number of sentences in a given speech that contain at least one keyword from the dictionary and express it as a share of the total number of all sentences in the speech. The higher the share, the greater the degree of ambiguity. We calculated a score for every speech in the database and then compared climate-related speeches to all other speeches.

Figure 13: Qualitative aspects of language in climate versus non-climate-related speeches



Source: Author's calculations.

The results are shown in Figure 13 which plots probability density functions (PDFs) for our speculative language score for both climate-related and non-climate-related speeches in the left panel. The right panel shows cumulative distribution functions (CDFs) for the two sets of speeches. Both the CDF and the PDF for the speculative language score for climate-related speeches lies to the right of non-climate related speeches. A simple t-test rejects the null hypothesis that the means (10.6 for climate-related speeches and 9.5 for non-climate related speeches) of these two distributions are same with a very high level of confidence (p-value of < 0.001). Moreover, a Komolgorov-Smirinov test under the null hypothesis that the two distributions are the same is overwhelming rejected. This statistical evidence suggests that central banks do indeed tend to use more speculative language when communicating about climate-related issues.

Climate change is a relatively new topic that is outside the traditional areas of central bank expertise. The risks associated with climate change reflect an exceptionally high degree of uncertainty, are difficult to measure, and past experience is not helpful for understanding how these risks might evolve in the future. For these reasons, some degree of ambiguity about the topic in public communication seems appropriate. That said, as central banks deepen their knowledge about climate-related risks, the language used in public communication should evolve. Going forward, sharper communication with more precise language can help establish credibility that central banks are being responsive to climate change.

[49] Focusing on use of modal auxiliaries (modalities) in speeches and texts is an area of speciality within the field of sociolinguistics (see, for example, Torres (2021), Jaime and Perez-Guillot (2015), de Waard and Maat (2012)). Within the economics literature, several papers apply these methods to explore central bank communication; Munday and Brookes (2021) uses the proportion of words that are modal verbs in a news article to gauge the uncertainty component of the news value of Bank of England publications. Kawamura et al, (2019) utilize modality in the Japanese language to measure ambiguity in the Bank of Japan's monthly economic report.

6 Conclusion

Text analysis tools were applied to a set of nearly 17,000 speeches given by over 100 central banks over the past twenty-five years. We presented a novel methodology to identify the subset of central bank speeches that address issues related to climate change. Once identified, these speeches were analyzed to assess the extent to which central banks talk about the use of macroprudential policy tools to address financial stability risks associated with climate change. We also examined a range of climate-related topics that go beyond financial stability and macroprudential policy.

Our results show that central banks have increased communication with the public about climate change, with an especially sharp increase in recent years. Central banks touch on financial stability concerns associated with climate change, but they rarely discuss macroprudential policy. Outside of these two topics, central banks touch on a wide variety of other climate-related topics, including: the impact of climate change on the economy, climate in the context of the financial system and supervision and regulation, financial innovation, and asset allocation. Advanced economy central banks tend to focus more attention on how climate change fits in with monetary policy and the central bank mandate. Emerging market central banks concentrate more on sustainable finance. To the extent that communication touches on direct central bank actions, the focus tends to be on microprudential supervision and regulation including topics such as supervisory expectations, stress testing, and mandatory disclosures of climate risk exposure. We also provide statistical evidence that suggests central banks tend to use vague and speculative language in climate-related speeches in a way that stands out relative to other speeches.

Looking forward, additional research is needed to better understand the role of central banks in reacting to or addressing climate-related issues. This additional clarity will help central banks to communicate more clearly about an urgent public policy issue and, in doing so, will help credibly establish that they are being responsive to climate change.

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Appendix A. List of Central Banks in Speech Dataset

Our analysis covers 108 central banks each of which has at least one speech in our Central Bank Speech Dataset. We classify these central banks into advanced and emerging market economies as in the list below. This classification is based on IMF's classification for their World Economic Outlook (see https://www.imf.org/external/pubs/ft/weo/2021/01/weodata/groups.htm).

A.1 Advanced Economies:

European Central Bank, Bank of France, Bank of England, Deutsche Bundesbank, Netherlands Bank, Bank of Italy, Bank of Spain, Monetary Authority of Singapore, Central Bank of Ireland, Reserve Bank of New Zealand, Bank of Japan, Bank of Finland, Federal Reserve System, Central Bank of Norway, Bank of Greece, Bank of Canada, Hong Kong Monetary Authority, Swiss National Bank, Reserve Bank of Australia, Sveriges Riksbank, Danmarks Nationalbank, Banco de Portugal, Central Bank of Malta, Bank of Lithuania, Bank of Israel, Central Bank of Iceland, Bank of Korea, National Bank of the Republic of Austria, Czech National Bank, Central Bank of Luxembourg, National Bank of Belgium, Monetary Authority of Macao, Bank of Estonia Bank of Latvia, National Bank of Slovakia, Bank of Slovenia, Central Bank of Cyprus.

A.2 Emerging Market Economies:

Central Bank of Malaysia, Central Bank of the Philippines, Reserve Bank of India, Reserve Bank of Fiji, Bank of Mexico, The People's Bank of China, Bank Indonesia, Bank of Thailand, Bank of Mauritius, Central Bank of Trinidad and Tobago, National Bank of Poland, Central Bank of The Bahamas, Bank of Albania, Central Bank of Kenya, National Bank of Serbia, Central Bank of Barbados, Central Bank of Nigeria, Central Bank of Kuwait, South African Reserve Bank, Bank of Zambia, Bank of Uganda, State Bank of Pakistan, Central Bank of Chile, Central Bank of the Republic of Turkey, National Bank of the Republic of North Macedonia, Central Bank of Sri Lanka, National Bank of Romania, Bank of Papua New Guinea, Bank of Ghana, Central Bank of Bahrain, Bank of Botswana, Bulgarian National Bank, Central Bank of the Russian Federation, Bank of Namibia, Central Bank of Curaçao and Sint Maarten, Central Bank of Argentina, Saudi Central Bank, Reserve Bank of Malawi, Bank of Jamaica, Central Bank of Solomon Islands, National Bank of Ukraine, Eastern Caribbean Central Bank, Central Bank of the Republic of Kosovo, Central Bank of Bosnia and Herzegovina, Central Bank of Nepal, Central Bank of Seychelles, Bank of Sierra Leone, Central Bank of Brazil, Magyar Nemzeti Bank, Central Bank of the United Arab Emirates, Croatian National Bank, Bank of Algeria, Central Bank of Samoa, Bank Al-Maghrib (Central Bank of Morocco), Bank of Mozambique, Maldives Monetary Authority, Cayman Islands Monetary Authority, Central Bank of Colombia, Bank of Guyana, Reserve Bank of Vanuatu, Bank of Guatemala, Bank of Tanzania, Central Bank of Armenia, Central Bank of Aruba, Central Bank of Belize, Central Bank of Bolivia, Central Bank of Ecuador, Central Bank of Jordan, Central Bank of The Gambia, Central Bank of Uruguay, National Bank of Cambodia.

Appendix B. Text Analysis Tools

This methodological appendix describe text analysis techniques used in our paper.

B.1 Text pre-processing

In our text pre-processing step, we follow standard practices such as methodologies described in Bholat, et al. (2015), Benoit, et al. (2018), and Grimmer, et al. (2022).[50] The raw speech text contains many symbols for punctuation and common words such as "the" and "and" which do not add analytical value. As such, it is common to pre-process the raw text to reduce it down to its most valuable content. Text pre-precessing is regarded as an important step in text analysis to make text data handy and informative.

First, we strip out symbols and numbers. Second, we remove a subset of words that are very common. Very common words, so-called "stop words," include articles ("the," "a"), conjunctions ("and," "or"), forms of the verb "to be," and so on. We use the stop-word lists based on the SMART (System for the Mechanical Analysis and Retrieval of Text) Information Retrieval System developed at Cornell University in the 1960s.

Next, we recast words into their common linguistic root using a Part-of-Speech (PoS) tagger of the spaCy package for Python (Honnibal, et al., 2020). It can identify the grammatical class (part-of-speech) to which each word belongs—nouns, pronouns, verbs, etc.—and convert them into their base form by a lemmatization algorithm that uses some rules and a dictionary of irregular patterns. For example. the word "banks" will be converted to "bank," the word "saw" will be converted to "see," and the word "meeting" is converted to "meet" or "meeting" depending on its use in a sentence. Lemmatization reduces the number of unique types of words that carry the same information and makes a large corpus more manageable.[51] Moreover, the PoS tagger can identify noun phrases by dependency parsing. It is extremely useful in our analysis to treat noun phrases such as "climate change" as a combined word rather than two separate words "climate" and "change". The noun phrase "financial stability" has a specific meaning for central banks, and we prefer to use it rather than two common words "financial" and "stability."[52]

Finally, we remove a subset of words that are very rare. Our speech corpus includes $2,176,150$ sentences and $992,740$ unique word types after pre-processing as described above. We remove less frequent words from the corpus depending on the characteristics of the analysis, especially for those that require large computational resources and/or where low frequent words do not play an important role (but rather give noise) in results. Specifically, truncating words that appear less than 5 times for word embedding or 100 times for score calculation reduces the types of words to $123,518$ or $10,965$, respectively.

[50] We use the R package quanteda v.3.1.0 (Benoit, et al., 2018) to process text data and calculate statistics across speeches and sentences.

[51] Word stemming, another popular technique that discards the end of a word using a simple rule, is regarded as an approximation of lemmatization.

[52] Another popular way to deal with noun phrases is to take all combinations of n-grams, which is a phrase of length n in a sentence. However, using higher order n-grams significantly increases the number of word types in the vocabulary, so it requires an additional treatment for removing less informative phrases.

B.2 Methodology for identifying climate-related speeches

As described in Section 3.2, our methodology to identify climate-related speeches consists of two steps: the first step is to calculate a *climate speech score* based on a seed word (*"climate change"*) used to detect a set of potential climate related-speeches (pre-refinement); the second step is to refine the set of climate-related speeches using our own dictionary developed by a semi-automated way.

B.2.1 Climate Speech Score

The basic idea of our automated scoring method is based on Laver, et al. (2003) and Watanabe (2018). In a political economy context, Laver, et al. (2003) construct word scores using pre-selected *reference texts* that are from opposite political positions and use the scores to scale ideological positions of target texts. Watanabe (2018) uses simple *seed words* to generate a large training dataset for scoring without additional human interventions. Watanabe and Zhou (2020) advocate that Watanabe's method is useful for topic classification in the sense that researchers can effectively classify texts into multiple categories consistent with their specific interests. We modify these methodologies to fit our task of single topic identification. Concretely, our methodology of calculating a *climate speech score* and using it to identify (pre-refinement) climate-related speeches is the following:

1. Using a single seed word (*"climate change"*), we divide all speeches into 2 sets: *speeches that include the seed word* (S_{seed}) and *speeches that do not include the seed word* ($\bar{S}_{seed}$).

2. We construct *climate word score* for each word i by calculating relative word frequency between S_{seed} and $\bar{S}_{seed}$ as follows:

$$\text{Climate Word Score}_i = \log(wf_{i,S_{seed}}) - \log(wf_{i,\bar{S}_{seed}}) \ ,$$

   where $wf_{i,S}$ is a normalised word frequency of word i in a set of speeches S calculated as the number of times word i appeared in a set of speeches S, divided by the total number of words in those speeches.

3. Using the *climate word scores*, we calculate *climate speech score* for each speech j by taking weighted average of word scores using (normalized) word frequencies as weights,

$$\text{Climate Speech Score}_j = \sum_i (\text{Climate Word Score}_i \times wf_{i,j}) \ .$$

4. We identify a set of (pre-refinement) climate-related speeches ($S_{climate\text{-}related\,(pre)}$) that have a climate speech score greater than 0 (i.e., $\text{Climate Speech Score}_l > 0 \ \text{ for } \forall l \in S_{climate\text{-}related\,(pre)}$).

B.2.2 Keyword Dictionary for Refinement

As described in Section 3.2, we find that the pre-refinement set of climate-related speeches successfully includes most speeches that we want to identified as climate-related, but it also includes lots of non-relevant speeches as well. We manually examine non-relevant speeches that have high climate speech scores and

select keywords to exclude these speeches. Therefore, our refinement step can be thought of as defining the boundary of climate-related speech identification. We take the following iterative process for defining a keyword dictionary and obtaining the final set of climate-related speeches with the goal of automating as much of the process as possible.

1. We define high score speeches for keyword exploration ($S_0 \subset S_{climate\text{-}related\,(pre)}$) using an arbitrary threshold for the climate speech score, set to two standard deviations over the mean for all speeches (0.48 for climate speech score).

2. We explore a set of keywords ($D_{ref} = \{k_1, k_2, \ldots, k_N\}$) from the high score speeches (S_0) by the following iterative process.

   (a) In Iteration n, we select the single most climate-relevant keyword k_n from a exploration set of speeches S_{n-1} based on word frequency (the number of speeches in S_{n-1} that include the keyword) and our judgement (where we know that keywords that have a higher climate word score are more likely climate-relevant).

   (b) As an exploration set for the next iteration (S_n), we collect speeches that do not include the selected keyword k_n from the previous exploration set S_{n-1}.

   (c) Continue to itterate until we can no longer find any climate-relevant word in the exploration set.

3. Using the keyword dictionary (D_{ref}), we identify a set of (after-refinement) climate-related speeches the subset of (pre-refinement) climate-related speeches ($S_{climate\text{-}related} \subset S_{climate\text{-}related\,(pre)}$) which contain at least two separate sentences with any identified keywords.

B.3 Methodology for identifying other topics in climate-related speeches

In Section 4.2, we employ the *k-means algorithm* to identify topics in climate-related speeches. This method, which is one of the most standard tools for clustering, is used in conjunction with a word embedding technique following works by Mikolov, et al. (2013) (known as word2vec) and Pennington, et al. (2014) (known as GloVe). The combination of these techniques is suggested by Grimmer, Roberts, and Stewart (2022).[53]

The word embedding technique maps a large corpus into low-dimensional word vectors such that words which have similar meaning/usage are represented by similar vectors. More specifically, the GloVe algorithm is based on the model that takes the form,

$$(w_i - w_j)^T w_k = \log \frac{P(k|i)}{P(k|j)} \ ,$$

where: w_i denotes a word vector assigned for word i, and $P(k|i)$ indicates a word co-occurrence probability that word k appears in the context of word i. If word i and j are used for the similar contexts, $P(k|i)/P(k|j) \to 1$ and $(w_i - w_j) \to 0$. Based on the model, the GloVe algorithm finds the word vectors by conducting a weighted least square regression that assigns small weights to frequent co-occurrences.

[53] See also Kozlowski, Taddy, and Evans (2019) and Dieng, Ruiz and Blei (2020) for potential applications of word embedding other than using for clustering.

To measure the word co-occurrence probability (as a matrix form $\mathbf{C}$), we count occurrences of any words located 10 words before or 10 words after the target word, weighted by a decaying factor (1/"distance between the words"). We set the dimension of the word vectors to 300. In our corpus, the number of word types in vocabulary is $123,518$, so the $123,518 \times 123,518$ sized word co-occurrence matrix can be represented by $300 \times 123,518$ sized set of the estimated vectors where $\mathbf{C} = \mathbf{v}^T\mathbf{v}$.

When we have vector representations of the corpus, we can then apply the standard k-means algorithm to the vectors in order to classify them. In our implementation, we calculate sentence vectors by simply averaging the word vectors assigned in words in the corresponding sentence.[54] Using the sentence vectors as an input, the k-means algorithm minimizes the following objective function:

$$f(\mu, \mathbf{t}, \mathbf{v}) = \sum_{i=1}^{N} \sum_{t=1}^{T} d(v_i, \mu_t) \cdot I(c_i = t) \ ,$$

where: N is the number of sentences, T is the number of topics (clusters), $I(c_i = t)$ is a cluster indicator that equals to 1 if sentence i is assigned to topic t, and $d(v_i, \mu_t)$ is the distance between a vector of sentence i and a cluster center μ of topic t is given by squared Euclidean distance:

$$d(v_i, \mu_t) = \sum_{m=1}^{M} (v_{i,m} - \mu_{t,m})^2 \ ,$$

where: M is the dimension of the sentence vectors (set to 300 in our word embedding step) and $v_{i,m}$ is an element of sentence vector for sentence i. Using the results of the optimization, every sentence is assigned to a single topic whose cluster center is the closest to the sentence vector.

We set the number of clusters $K = 20$, and manually label the estimated clusters based on word clouds of sentences in the corresponding clusters as describe in Section 4.2. We discover 8 meaningful topics shown in Figure 8, while other 12 clusters include specific names of countries and central banks, language frequently used in speeches (such as “today,” “gentleman,” and “attention”) or general words (such as “figure,” “percentage”, and “year”), and are therefore not of our interests (i.e., they are so-called “garbage topics”).

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Appendix C. Climate-specific Policy Tools

In our analysis in Section 4.1, we identify 65 keywords that indicate climate-specific policy tools from a total of 1,498 climate- or green-related keywords (i.e., "Climate XXX" and "Green XXX") found in our corpus. We classify them into 6 categories: climate disclosure, climate risk management, green taxonomy, climate research, climate scenario analysis/stress testing, and green monetary policy/capital allocation. Table C.1 shows a complete list of those 65 keywords and their classifications into 6 categories.

Table C.1: Keywords for Climate-specific Policy Tools

Category	Climate-related Speeches	Keywords
All Speeches	555	
Climate Disclosure	113	climaterelatefinancialdisclosures, climatedisclosure, climaterelatedisclosure, climaterelatefinancialdisclosure, climaterelatedfinancialdisclosures, climateriskdisclosure, climatereporting, climaterelatereporting, climaterelatereportingobligation, climaterelatereportingrequirement, climaterelateriskdisclosure, climaterelatedisclosurerequirement
Climate Risk Management	48	climateriskmanagement, climateriskanalysis, climateriskassessment, climaterelateriskmanagement, climateassessment, climatechangeriskassessment, climaterelateriskanalysis, climaterelateriskassessment
Green Taxonomy	29	greentaxonomy, greentaxonomygreenbondstandard, greenlabel, greenloantaxonomy, greencertification, greencredential, greencriterion, climaterelatecriterion, greenstandard
Climate Research	12	climateresearch, climatemodel, climatemodelling, climatechangeanalysis, climatevulnerabilityassessment, climatedataanalysis, climateriskassessmentmodel
Climate Scenario Analysis / Stress Test	74	climatescenario, climatescenarioanalysis, climatestresstest, climatestresstesting, climaterelatescenario, climatescenarioexercise, climaterelatestresstest, climateriskscenario, climatebiennialexploratoryscenario, climateriskstresstest, climatechangescenario, climaterelatescenarioanalysis, climateriskmanagementscenarioanalysis, climateriskscenarioanalysis, climatedrivescenarioanalysis, climateriskstresstestanalysis, climatesensitivityanalysis, climatestresstestingsensitivityanalysis
Green Monetary Policy / Capital Allocation	12	greenmonetarypolicy, greenqe, greenassetpurchaseprogramme, climategreeningmonetarypolicypolicy, greeningmonetarypolicy, climatechangefundprovisioningmeasure, greenmonetarypolicyassetportfolio, climatebasecentralbankpurchase, climateorientpurchase, greenassetpurchase, climatelinkcapitalinstrument

Appendix D. List of Reviewed Speeches

Speeches Reviewed in Section 3.3 (Validity Checks)

[1] Hendar (2015) "Increasing cooperation between Indonesia's central bank and state police," Bank Indonesia, https://www.bis.org/review/r150309c.pdf.

[2] Lautenschlager, Sabine, (2017) "Cyber resilience - a banking supervisor's view," European Central Bank, https://www.bis.org/review/r170629a.pdf.

[3] Waas, Ronald, (2014) "Handling alleged payment system and currency exchange crime," Bank Indonesia, https://www.bis.org/review/r141023b.pdf.

[4] Diokno, Benjamin E., (2021) "Sustainability in investing," Central Bank of the Philippines, https://www.bis.org/review/r200807m.pdf.

[5] Elderson, Frank, (2018) "Let the future of finance be that of financing the future," Netherlands Bank, https://www.bis.org/review/r180503h.pdf.

[6] Lane, Philip R., (2016) "Dual perspectives on the insurance sector – consumer protection and financial stability," Central Bank of Ireland, https://www.bis.org/review/r160613c.pdf.

[7] Nabiullina, Elvira, (2021) "Speech at Association of Russian Banks," Bank of Russia, https://www.bis.org/review/r210427e.pdf.

[8] Olsen, Øystein, (2021) "Monetary policy strategy - from mandate to decisions," Norges Bank, https://www.bis.org/review/r211112f.pdf.

[9] Gang, Yi, (2021) "Hong Kong's positioning and prospect as an international financial centre," People's Bank of China, https://www.bis.org/review/r211216o.pdf.

[10] Trichet, Jean-Claude, (2008) "Monetary policy in challenging times," European Central Bank, https://www.bis.org/review/r080606c.pdf.

[11] Yue, Eddie, (2021) "Hong Kong's positioning and prospect as an international financial centre," Hong Kong Monetary Authority, https://www.bis.org/review/r211209d.pdf.

[12] Macklem, Tiff, (2021) "The long and short of it - a balanced vision for the international monetary and financial system," Bank of Canada, https://www.bis.org/review/r211008c.pdf.

[13] Haldane, Andrew G., (2010) "The $100 billion question," Bank of England, https://www.bis.org/review/r100406d.pdf.

Speeches Reviewed in Section 3.4 (Summary Statistics)

[1] Carse, David, (2000) "Environmental issues and their implications for financial institutions in Hong Kong," Hong Kong Monetary Authority, https://www.bis.org/review/r001129c.pdf.

[2] Goh, Chok Tong (2007) "Staying ahead of the Asian curve," Monetary Authority of Singapore, https://www.bis.org/review/r071105b.pdf.

[3] Boediono (2008) "Macroeconomic impact of climate change - opportunities and challenges," Bank Indonesia, https://www.bis.org/review/r080901c.pdf.

[4] Draghi, Mario, (2009) "The financial crisis - impact and responses," Bank of Italy, https://www.bis.org/review/r090507b.pdf.

[5] Tarantola, Anna Maria, (2010) "Women nurturing sustainable development," Bank of Italy, https://www.bis.org/review/r101208g.pdf.

[6] Provopoulos, George A., (2011) "The impact of climate change in Greece," Bank of Greece, https://www.bis.org/review/r110614a.pdf.

[7] Ibrahim, Muhammad, (2012) "Role and opportunities of the financial system in supporting green technology," Central Bank of Malaysia, https://www.bis.org/review/r121004g.pdf.

[8] Rambarran, Jwala, (2013) "Generating more inclusive economic growth through science and technology," Central Bank of Trinidad and Tobago, https://www.bis.org/review/r130806a.pdf.

[9] Padmanabhan, G., (2014) "Corporate sustainability a panacea for growth - values, convictions and actions," Reserve Bank of India, https://www.bis.org/review/r141021d.pdf.

[10] Carney, Mark, (2015) "Breaking the Tragedy of the Horizon: Climate Change and Financial Stability," Bank of England, https://www.bis.org/review/r151009a.pdf.

[11] Carney, Mark, (2016) "Remarks on the launch of the Recommendations of the Task Force on Climate-related Financial Disclosures," Bank of England, https://www.bis.org/review/r161216h.pdf.

[12] Stournaras, Yannis, (2017) "Climate change - challenges, risks and opportunities," Bank of Greece, https://www.bis.org/review/r170726e.pdf.

[13] Carney, Mark, (2018) "A transition in thinking and action," Bank of England, https://www.bis.org/review/r180420b.pdf.

[14] Njoroge, Patrick, (2019) "The importance of green finance guidelines as Nairobi seeks to become a global hub," Central Bank of Kenya, https://www.bis.org/review/r190321d.pdf.

[15] Orr, Adrian, (2020) "Progressing climate action by driving transformational change," Reserve Bank of New Zealand, https://www.bis.org/review/r201104f.pdf.

[16] Kuroda, Haruhiko, (2021) "Addressing climate-related financial risks – from a central bank's perspective," Bank of Japan, https://www.bis.org/review/r210326c.pdf.

Speeches Reviewed in Section 4.1 (Climate Change, Financial Stability, and Macroprudential Policy)

[1] Lagarde, Christine, (2021) "Macroprudential policy in Europe – the future depends on what we do today," European Central Bank, https://bis.org/review/r211208i.pdf. *"Effective climate policies would also benefit the financial sector. But macroprudential policymakers have a part to play, too, in identifying and mitigating the financial aspects of climate-related risks."*

[2] Lane, Philip R., (2019) "Climate change and the Irish financial system," Bank of Ireland, https://www.bis.org/review/r190206b.pdf. *"This calls for ongoing monitoring of climate risks, together with the development of climate-driven scenario analyses and stress tests. By extension, the results of such analyses may call for the appropriate macroprudential policies to mitigate these risks."*

[3] Stiroh, Kevin, (2020) "Climate change and risk management in bank supervision," Federal Reserve Bank of New York, https://www.bis.org/review/r200309b.pdf. *"...supervisors can focus on identifying and managing risks, both microprudential and macroprudential, that emerge along a transition path to a more sustainable economy"*

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